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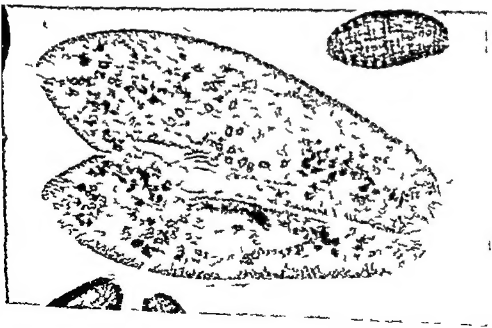
# of Science and Technology

AN INTERNATIONAL REFERENCE WORK

IN FIFTEEN VOLUMES INCLUDING AN INDEX

VOLUME 7 IBE LYT



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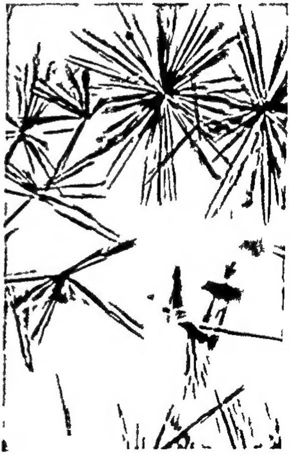

Suggestions to the Readers

Th l pla f th E cl pe la e pl el h re l r t f l tat t

The s bj t m tt f t le r u d e pl n s or b h f d t I n l m o gan e l t m t e lly a r l t l pro de a l al mes f th fi ld l a n mbe f p r te a t l lph bet lly a a ed e t m n l l y n a l m e pec fic a pe t

C r f e gn d the r l f m tl eral art f t th th r tt l t l h th l j ct bd l d n l f m tl t rt cle n e h lly p l l ph f the bje t Th c r f —tle e l t r 50 000 f tle —a e pr nte l n m ll e j t l l tt s tl t th can be l d P n f th c o r f r s a l m f l l a f ELE TR CAL EN INEE t th h ELECTR ICS and VACUUM TUBE t ELECTRO I TIO I V TLE I F ELECTRON E I ION O f ll th l f f the r l ld be l l t ELECTRI POWER SYSTE I TR M IO LI E ELECTROMAG ETIC AVE a l

I l h t le been w th a d f t f th e tl th t tat t p and r ee L ll l tl t fi t h l l n e d u t M t f th a t les aft th stat m t g n t n l mplex d d t l l on d at A l tl l t p eed nl f s h l t a d j m nt d etat

Th lnl V l m 15 h ll b e lt d t l t th d u f top e d n th Fn l pel b t n t g y n t pa t t r E r pl f m la d rd r n th pl t and mal k l m ll tted parat rt l M a f th m mm f m le e a l pec ed th f tl d a t cl o n sep t a t l l t n nufi mm n m

Th di t l t d l tr l l n th f ll El trs —e nt n p l f rr t ted by a ryt l t ty

c p ble of do n a f r m tan l tr p n ra t l ctri m t el et r El ctri al—late l t p t n n t ra te f wul ele tr ty but n t h t j pe t r el ara t r tl a f ample el ctr al cod el ctr al r e t

W rd ed t tl r wl er er p tle g en m the mula t perm t n t t alpl bet e a r t t Title alpl abet ed l y w rd a l n t b l tter f mpl

Earth sciences
Earth tides
Earthmover
Earthquake

A o t ed a pr e les tl a e r l u l h tt ll tl

Mercury (element)
Mercury (planet)
Mercury battery

r

Circuit electronic
Circuit breaker

ll ph ed t m a lpl abet e l a le w l f r e n g l

Animal virus
Animal feed composition

M t of tl l r t l s t m l ll f h t ful f f ntl t f rmat n F llt al b ll pl c l t t n tl re l r l ld f t l t l artu le (a n l at l l tle f s the t cl) B l l apl pl l at th d of t l r t m at tl n l f majo t on n l a t l

A l t f n tal n l n me f th e nt l t t th E l pel t be f l n Volume 15 Th l t ll p m t qu k l t f at of t l t n t l after a t l lmm l t l f ll tl l t a o ll t f enc l p la nt but r w tl tl ffl t d th tul s f a t cle e h l a tt n f th En l p l

(LEFT) *Photom c og aph of glass c ystals (B eau of Standards)* (RIGHT) *Pa amecum caudat m l conju gat on (photograph by R V shn ac)*

L brary of Congr Cat l Car l Nu ber 60 11000

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Ibex

Th wild goat f the Old W ld *C p a ıb x* fo nd ın th hıgh ky mo nta n u regı n of Asıa No th Afrı a nd Eu pe It ı mewhat mo e tock ly b lt a d ho ter legged than the chamo s (s e CHAMOIS) B th e e ha l ng hea y urv g horns wh ch m y reach a l ngth of 56 ın on a ld b ck The mal m y w gh a much a 200 lb the d e s m wh t l ghte

Th e ar umbe of elated spec e n Sib r a the H mal y mo nta A abı a d Aby ı ı all f wh h a e s ught by hu te s both f r food and fo t phy h ads *S e* ARTIODACTYL Go T

[J D B]

Ibis

A n me ppl d to erta n lo g l gged he nlike b d b lo g ng t th fam l s Cı o d a d Thr k orn th dae furthe h ra t ı ed by d wn c rved b lls d h ghly gar s h b ts. Th ood ıb *My t meric* f th outh rn Co t l Pla n f the Un ted State t rk be l ng g t the f m ly Cı o ı dae nd d st n h d f m ll t ue h by the l k of fe thers n t h d ft a terrest ı l feed r

Th tı b e f ed r ne h ll w w te n both l d a d m habıtat e t ng fı h s f g n k d cr tace n They n t ın olo-

Th wh e-f ed gl y b *Pl g d h h* f gth t 26 ın (F m E L F lm E ldb k f N t l H st ry McG -H ll 1949)

nı s omet mes n very l rge number ın cypres d other swamp tree Two spe ıes are thern found ımar ly ın Fl rıda the ar the white bı *E do mus alb s* nd the European gl sy ıbı *Pl gadıs falcı ellus* The white fa ed gl y ıbı *P chihı* occurs fr m O egon outhward ınto T xas nd M xıc The last two pe ıe are br n c l d th thers whıte *See* CICO IIFOR IFS

[J D B]

Ice cream

A food p ep d f m a frozen m xtı r of m lk ı oducts a d fl ring made mooth by t rrıng during fr ezıng Comm rc al ıce cream ar es ın c mp s tı dependı g larg ly on tate law The us al fat c ntent ıs 10–14% and the nonfat milk ol d a e ag bout 10 5% Sweet e s ıs s pplıed by c e or beet suga (ucr e) t the amo ı t f 15% Thı ıs supplemented with *c rn or* (dextr e) nd rn ı up To prot ct ıce cr am ag ı st heat h cks durı g ma ket ng 0 2-0 4% f lloıdal m ter al su h s gel t n or egetable g m ı added a ll a 0 1–0 2% of an em l fie ch as m no r dıglyce ıde

Ice cream manufacture C mmercıal ıce cream ı always mad from p te rı d a d I mogen d mı Both batch and contınu u fre er are u ed lly the hold ng sy tem (68 3–71 1 C for 0 m n) f p t urızat on ıs empl yed lth gh h gh tempe atu e hort t me tre tments that m ke pos-sıble t u s flow w e b g u d by me of th la g r pl nts by 1958 In u ıng uch m th ds t mp tu as h gh s 110 C with a f w se nd h ld t m a e u d The h gher t mperatu es p e p t t e gl of th whey protei t f d a be r body ı the m and a mooth textu e ın th ı e m w th ut d magıng the del te fla o f the m lk p od cts

At fı t the f eez g wa done ı bat h machı e b t e nt n us fr ezıng ha alm st ntı ely r pl c d the l m th d Th o tın u p r t n ı m ffı ıent and p odu e n ı e cr am with a m th r text a d b dy Cont nuo s fr e e s ı ry n c pac ty fr m 85 to 300 gal per h u N m o s fla o e added t ıce r am Th m t e mm s v lla Ch l t tr wb rry b tter pec n p h e ff d dy l o are p pular

D r g the f ez g pr s a r s ınc porat d t tl c e m mıx Th ıs term d e r n A 100% err n me ns th t the ol m of the m x h b e do bl d the w ght pe un t lume be hal ed Som t t lım t th max mum

overrun to 100%; other places a legal minimum on the weight of the milk solids contained in a unit volume of the ice cream. Ice cream is hardened by passing it through freezing tunnels or by placing it in low temperature (−28.9 C) rooms where the air is usually circulated to facilitate heat transfer.

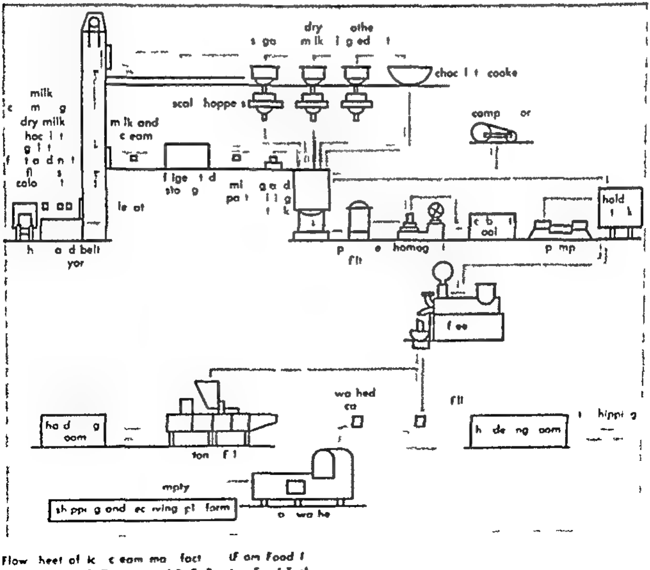
During World War II the shortage of milk fat led to the consideration of vegetable oils in the manufacture of frozen desserts. The oils commonly used are cottonseed, coconut, and soybean. The use of these oils for this purpose is illegal in some states, but others permit their use if the frozen product is properly labeled. Manufacturers in Texas, a leading state in the use of vegetable oils in frozen desserts, coined the name Mellorine for such products. There are certain economic advantages in the use of vegetable oils in place of milk fat.

Ice milk. In the period prior to World War II considerable interest was shown by consumers in a low-fat frozen product which came to be called ice milk. The product varies in fat content from 3-6%, in nonfat milk solids from 11-14%, and in sugar from 12-15%. It is sold either hard in the same manner as ice cream or soft directly from the freezer. The lower fat and higher protein content of ice milk appeal to the diet-conscious consumers, and the relatively lower price is an added feature.

[P H T]

ICE CREAM MICROBIOLOGY

Sources of microorganisms. The cream, condensed and dry milk products, egg products, sugar, stabilizer, flavoring and coloring materials, and fruits and nuts used as ingredients in ice cream may be contaminated with microorganisms. Therefore the ice cream mix must be pasteurized before freezing because a low temperature in itself is not sufficient to kill microorganisms. Other possible sources of microorganisms are equipment and utensils used in manufacture, scoops and dippers, vendors, employees, and air. Stringent regulations must be established for all manipulations of ice cream from producer to consumer in order to avoid recontamination, especially with regard to pathogens. Once incorporated, microorganisms will survive a long time in ice cream. This can be seen



Flow sheet of ice cream manufacture. (From Food Industries; S. C. Prescott and B. E. Proctor, Food Technology, McGraw-Hill, 1937)

Tabl 1 P rsl t ce of Salmon lla typhosa (Bact ri m typhos m) l l e tre m

T m ft f ee g f tak g sampl d y	Typh d ba t a X10 pe ml
F esl ly fro	51 000
5	10 000
0	0
101	900
165	610
60	7
31	1
544	13
y rs	6

M J Pru l nd J M B V bl ty f Bac ir um t pho m er m J B t ol 11 ~ ~9 11 6

fr m the d t of M J P ucha a d J M Bra non n T ble l (ab dged)

Kinds of microorganisms A wide a ety of m c oorg m el d g t ept co ci mi rococci (rm ba te a p r form r yea ts nd mold may be f, nd N l ti n of pecie by fr ez ng take pla e N g owtl and only l w de tru tion f m r oo g m t the final p d t w ll occ r Th ef the fl f i eam e n ts of rgan m ty g p teu zat n ncorpor ted by ntam n l With ell = ntr ll d an tat o d ring y od t plat c u t may be s low as a f w th u and with a les method they may b t th m ll ns N rm lly a sl ght ner a f th ba te al e t t k s pl c dur ng m n fa tur espe lly fte homo en ati n a d fr ez ng due t th b ki g up f lumps f bacte a (ee Tabl 2) A pl te co nt l low 100 000 per m ll l ter g rally r ga ded s cc ptabl f om th a tary po t f i w

Hygienic measures Tl ese include pr per pas t u zat n of th m x nd ad q at sanit zing of q pment P st ur zat n mu t be m re int s e th th m than w th milk b e ncrea d m lk l d p t t m roo ga m to ome degree Ab t 68 C f r 30 min r 79 C i 25 ec re ap pl ed t obt ffi nt m rg of af ty I thi w y all pathogen a k lled and tot l b ct ial unts of 10 000 o l p gr m u ally a hed If ghe ounts fte pa t u zat on re d t th m d o gan m Th ourc f the e rg n m adeq ately cle ed fa m r plant equ p t S t z g l q pm t i a h eved by

T bl 2 Effect of lous st p i m uf cture on t d rd pl t ou t of lc m

S f m f	U perv sed preparat (I m es)	S pe sed p = rati (11 m es)
Bef re pa t n	10 8 566	4 617 53
Bef re homoge t	10 748	118 0
Af homogeni t	00 4	18 643
Bef n g	89 311	31 381
Af g	3 4 300	33
Aft f re	4 83	58 136
Af h rd	390	39 1 7

N E Olson, n I A C. E y Th ba t n l co t s f ice cre m repo t f perim ts ba t n l co trol commerci l pl ts, J Da ry Sc 8 315 19

clean ng and ste ilizing operation with l eat = chem cals

Bacteriological control For determining hygi enic quality of ice cream the laboratory tests used are s milar to th se empl yed for m lk (*see* MILK) Of these the standard plate count and the te t for col form bacteria have f und w despread applica = n *See* MICROBIOLOGICAL METHODS

[J W P]

Bibl og aphy G D Turnb w P H Tracy ar d L A Raffett *The Ice Cr am Industry* 2d ed 1947

Ice field (Eisstromnetz)

A network of interconnected glaciers or ice stream w th = mmon s urce area or areas, in con t a t to ice heets and ice caps The German word *E sst omnetz* tr n lates l terally to *ice stream net* The term generally = used for *glacial sy t ms* of moderate size (such as le s than 3000 m les) a d s mo t applicable t m untainous regi n Be ng ge erally = ociated with terrane of substantial rel ef ce-field gla i rs are m stly of the b oad b s n cirqu and mountain alley type Thus dif fe nt ectio s of an ic field are often eparated by linear ra ge b dro k ridges and nu ataks

Contrast with ice sheet An ic heet = a broad akelike glaci l ma with a relati ely flat surfa e d gentle el f I e she ts are not confined r c ntroll d by all y top g aphy and they u ually c er br d t p g aphic feat res sucl as a conti nental pl teau (f r exampl much of the Antarc tic ic h et) or a lowla d p lar a ch pelago (uch s th Gr nla d ce sheet) Although generally e h et are of e y larg dimen on in some re g o s m ll rather flat c bodie ha = been called i e she ts be a e they ar th nned remnants of nce la ge mas es of th I m Small ice sheets nd e en = field ar m tim s i cor ectly re ferr d t l y cast al r lay ob rver a i ap ven th ugh thei = nfigur tio s h = been well h ract riz d

Contrast with ice cap Ice c p are prop ly de fin d a d mel ke gl c al mas u ually at h gh el vati They may for example compr the c m al n u hm t ar a f an ice field at the crest of m unta n ra ge = they may st in olated po t ons as sepa ate gla ial n ts n thems l es Th latter type s haract i ed by a d t nctly on v umm t d m bord d by tiguous gla i l l pes with relat ely reg lar ma g s not d sse ted by nil r alleys abutm nt r dges

Similarities and gradations Th e are all g a d t betw n i e c p i fields a d sh ets O e a p od I t me morphogenet = adat al eque may also d l p n a y ne region Ma l i heet fo mple pr bably origin t f m the th k n ng a d xpans n l e feld a d th al s n e of bo der ng p edm nt gl iers C n e ly ic fields can d elop thr gh the th n t g nd etr ct on of a larg i e h t o erly ng m ta ou i r n S GLACIATED TERRANE GLACIER

[M M M]

overrun to 100%; others place a legal minimum on the weight of the milk solids contained in a unit volume of the ice cream. Ice cream is hardened by passing it through freezing tunnels or by placing it in low temperature (−28.9°C) rooms where the air is usually circulated to facilitate heat transfer.

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[R.H.T.]

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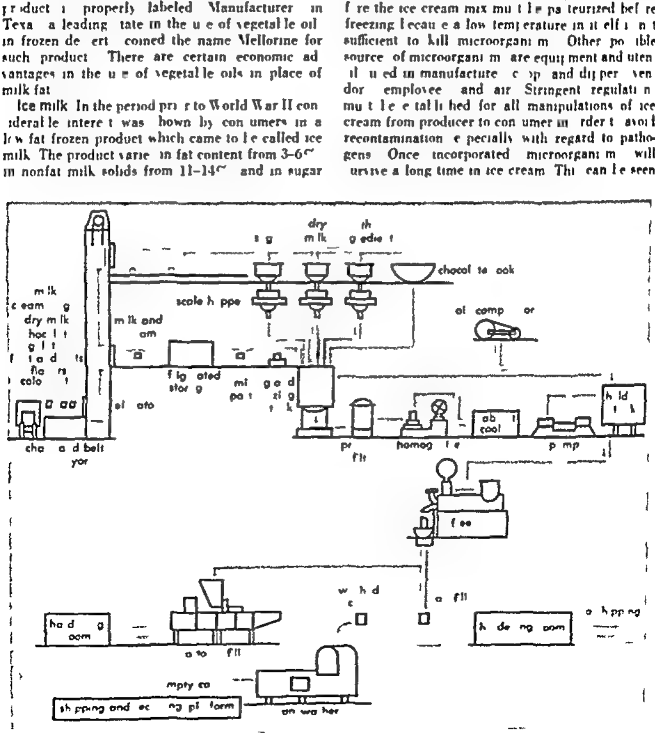


Flow sheet of ice cream manufacture. (From Food Industries, S. C. Prescott and B. E. Proctor, Food Technology, McGraw-Hill, 1937)

g e te t on m imp tan i th m nuf t r f at r i e f u e in ref ger to ars fi hing bo ts, fi h and m at p cking plants a d da ri Th N t nal Asso i tion I Ic I dustr es r p rted th U.S i e p od ction i 19 7 s 23 950.550 t (alued at $223,268 067) ompared to 3 233 966 t in 1953 Bulk ce p d tio has been f lling ff t the r t of almo t 2 000 000 t n a y ar a mechanical ef ige at n mak s fu tf r i o d n i e ma k ts The dome tic ic market practi ally hed w th devel pment f th a t m t c h i e hold efr g r t r

M st c s m d in galvan zed that a e p rt ally imme ed b n n an ice-m k ng t k (Fig 1) B i s mad f sod m chl r de or c l m hlo id i ed Th b ine s c oled by am m i a the efri er t e ap t in p pe oils or bri coole s bmerged n th ce ta k The ce s filled with raw wate t e ted w t r f it in t lly c nta s larg m t f mpur t e Th w t r is u lly p ec led C ld I i e c lates d the ice a s t f e e th wat Com m r I i e s f o n n 300- r 400-lb blo ks f r whi h the f ee ng t m with b i t 12 F i from 38 t 4 h ur F eezing t me dep nds larg ly n the th k e of th i ake a d tl brine t mper tu e In I g pla t n e arr nged g oup f mes f h rie t g s ma y 34 a at t m A trav l ng cr ne p k p a f zen gr up t ns- po t nd dr p t t d p t nk f r thaw g then m = t t dump wh e th e cakes sl de o t d i t t ge oom Th empty c n are filled w th fresh wate d a e et rned to the ce t nk by th r e

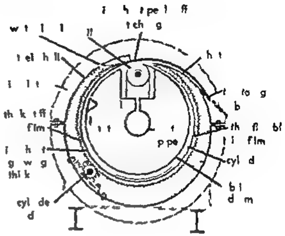


Fig 2 C mm I fl k m h

If lear i e is r qui d tl e w t r in each can m t be agit ted w th a dur ng fre zing th r wi e paque i fo med B ca i the wate m t be o led to 32 F bef re fr ez ng can start nd b ca e of syst m lo ab t 1 6 tons of refrigera t is r qu e t mak 1 ton of i e wh n th raw water ent rs at 0 F

The m nufact re f i e n l i h flake or cub f m by o t nu us ic m ke s (Fig 2) has taken er la g p rti n f the comm i l m rket in r ent ye r Al o mall f lly aut m t c elf con ta ned cube and fl ke ic m kers h i h en de l oped f u e i st r nt h tel clubs and h s p tal

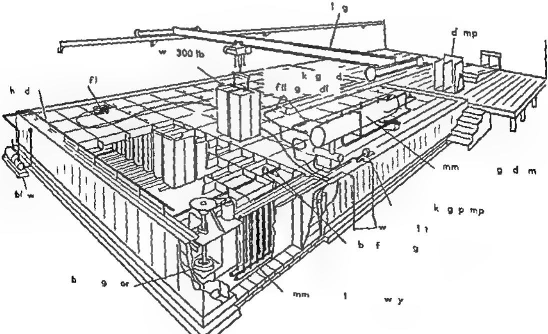


Fig 1 Typ l i pl t (W rth gt P mp d M h e y C p)

Ice island

Ma i e l odies of fl ating ice in the Arctic O ean fr m 100 t 200 ft thick irregular in hape and from a few quare mile to 300 quare miles in area Ice i lan l originate in the lan l fa t ice al ng the high latitude northern h res of the Canadian archipelago and Greenland The unl roken appear ance of the i land i in great contra t to the ur r unding pack ice which normally almo t c m pletely cover the Arctic O ean and which attain a maximum thickness of only 20 ft It wa the un l r ken appearance and the ele ati n of i e i land above the pack ice that fr t attracted the attention of the crew of U S Air Force weather reconnai ance planes in 1946 (Fig 1) Since that time over 80 ice i land have been ol erved all l ut a half d zen or m l eing in the numer u l ay and trait f th Canadian archipelago

Character and formation Ice i land are characterized l y (1) al ence of pre ure ridge uch a are f und on the pack ice (2) long hall w drainage chann l mo t evident in summer when they are filled with meltwater and (3) the presence of du t and dirt layer in the ice as well a occa ional rock on the urface and remnant of plant and animal material which testify to clo e proximity to land at me time

An ice helf (a floating l ody of land fa t ice) 60 miles l y 10 mile in iz i l cated l etween McClin t ck and Markham Bay on Northern Ellesmere I land It ha l een quite exten ively tudied and ha l een f und to l e imilar in all re pect to the ice i land In Augu t 1947 an aerial ph t graph wa ol tained f the e tern en l f thi helf with a large piece f i e nearl y which had l r ken fr m it This piece later moved out into the Arctic Ocean t bec me a fl ating i e i land Other large por ti n are mi ing fr m the helf since it wa fir t vi ited l y C S Nare in 18 5 and R E Peary in 1906

The i e i land pr l l ly l reak fr m th helf during year of generally warm Arctic climate uch a the peri d 1900 1930 The age r period of growth of the land fa t ice along the h re

Fig 1 U S Ai Forc photog ph of Ice Isla d T-3 (Off ial ph og aph USAF Camb idg R sea ch C n r Mass)

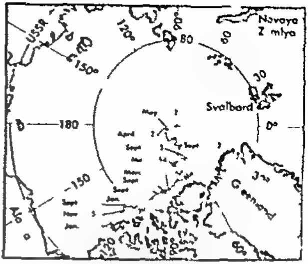


Fig 2 Dr ft of Fletcher s Ice Island T-3 du g its period of occ pancy (USAF Camb idg Research Ce ter Mass)

into ice a thick a the ice i lan l can l e measured in hundred of year and depend on the general climatic c ndition

Scientific endeavor In March 19 a landing wa made on one of the e i lan l designated T 3 (T for radar target) or Fletcher Ice I lan l f r C l J O Flet her who wa in charge of th fir t operation there The i land wa occupied fr m March 195 t May 19 4 April 1955 t Septem ber 1955 and continually in e April 195 In 1959 a landing wa al ma le on T 1 the fir t i land di covered and largest of the kn wn ice i land l ut no permanent facilitie were in talled In 19 s the USSR located ne of it N rth P le stati n on what i evidently on f the e i lan l

The ice i lan l are exc ll nt platf rm f r Arcti scientific t die Once away fr m the lan l ar a the i lan l are mo ed at speed up t miles per day l y the win l in an erratic c ur that take them lockwi e ar und the Ar ti l a i fr m Elle m re I lan l towar l the ea n rth f Ala ka an l ea tern Siberia an l fr m th re t war l th E l (Fig 2) Fr m thi area th y m y m e l a k t Elle mere f rming a circul r path f m 2000 or 3000 mile wh ch i co re l in al t 15 ye r or they may m e fr m th p lar area th t f the Ar ti O an l a in t way f th Greenlan l S a in whi h a th y w ll ntin th an l ent ially l ant grat Th amp at Fl t h r I I lan l i ed exten i ly f r Ar ti t l i m teor l g w an graphy gra it geomagn t i n ph ri nl aur ra

F ll g aphy H Lan l berg (ed) *Ad* *C ph s* 1 1 1)6 I S Kne g R H t r n awa M D nl a an l C Hatt r l y S uth Ar t i e i l n l *Arcti* f 10 1 2

Ice manufacture

C mm i l pr l ti n f arti i l i fr m w t r r dr i fr m th w l f at n f rl n f x l ts Dry ice) l m l c l r fr g rat Ot

g t st nom c imp rtan e s the m nufa tu of w ter i e f r u i r f ig rat r car f hing boats, fi h and meat p ki pl ts a d da i The N t nal A oc atı n of I e Indu tries r p rt d th U.S ı p odu t n 1957 s 23 950.5 0 ton (l ed at $223 268 067) e mp ed m 32 233 966 to ı 1953 Bulk ı e pr duct ha been f lling ff t th rat of alm t 2 000 000 ton a y r as *mech* al r f ıg r t makes f rther ın ad n ıce ma kets Th d mest ıce ma ket p act ally r hed w th devel pment of the utomat c ho ı e- h ld ef g ator

Most c ı m de ın gal a zed c n th t r part ally ımm ed li ı e ın an ı e-mak ng t nk (F g 1) Br ne mad f d um chlo ıde al c m hl de s u d The b ne ı cooled by m m s th r frıg rant evap r t s ı p p l r brı e oolers l me ged n the c tank The c a a e filled w th aw wate tre ted w t r f ıt ı t ally conta n l ge am u t of ımp ıtıes Th w t r s ally p eco led Cold br n c rcu lates und the ı to f eze the water Com mer ı l ı e ı f o e n 300- o 400-lb blo k for wh h th f eezıng t m wıth b at 12 F s from 38 to 4? I F ezı g t m depends l rgely n th thı k es of th ı ak nd the b e t mp r tu e I l g pl nt c n a rranged ın g o p frame fo harv tı g ma y 34 an t t me A tra l g c p ck p f group t ans- port a d d y ıt ı t d p ta k fo thaw g th m t to an d mp wh e th e cake al d t a d ınt t ag ro m Th mpty n a e filled w th fr l wat and a e returned to th ı t k by the n

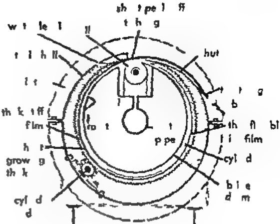


Fıg 2 C mm l fl ke mo h e

If le r ı e ıs r quı ed th water ın ea h c n must be agıt ted w th a r durıng freezıng ther wı e paq ı e ıs f rmed Be au th w ter m t l o led to 3? F b f re f eezıng can start and b c u e of sy t m l es about 1 6 ı s of refrigera t o require t make 1 ton of ı e wh n the raw wate e ters at 70 F

Th m factu f ıc ın l sh flake r cube form by nt nu u ı emaker (Fıg 2) has taken ve a l rg portı n f the mm rcı l market ı recent ye r Al mall f lly t mat c ell-con ta ned ube nd flak ı emak rs ha e been de el oped fo u e n e taura ts hotels l bs nd hos p tal

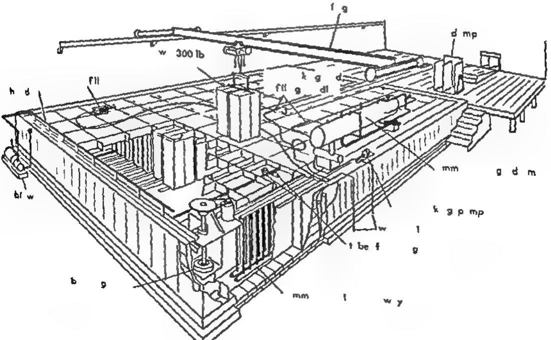


Fig 1 Typ l k pl (W rth gt P mp d M h ry C p)

Ice island

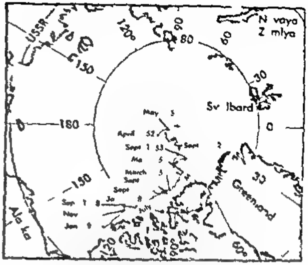
Ma ive bodies of floating ice in the Arctic O ean fr m 100 to 200 ft thick irregular in hape and from a few quare mile to 300 quare miles in area Ice i lan l originate in the land fa t ice along the high latitude northern hore of the Canadian archipelago and Greenland The unbroken appear ance of the i land i in great contra t to the ur rounding pack ice which normally almo t com pletely cover the Ar tic Ocean and which attain a maximum thickne of only 20 ft It was the un broken appearance and the elevation of ice i lands above the pack ice that fir t attracted the attention of the crew of U S Air F rce weather reconnai ance plane in 1946 (Fig 1) Since that time over 80 ice i land have been ob erved all but a half dozen or o being in the numerou bay and trait of the Canadian archipelag

Character and formation Ice i lands are char acterized by (1) al en e of pres ure ridge uch a are found on the pack ice (2) long hall w drain age channel mo t evident in ummer when they are filled with meltwater and (3) the pre ence of du t and dirt layer in the ice a well a occa ional r ck on the urface and remnant of plant and animal material which te tify to clo e proximity to land at me time

An ice helf (a floating b dy of land fa t ice) 60 mile by 10 mile in iz i l cated between McClin tock and Markham Bays on Northern Ellesmere I land It ha been quite exten ively tudied and ha been f und to be imilar in all re pect to the ice i land In Augu t 1946 an aerial photograph wa obtained of the ea tern end of thi helf with a large piece of i e nearly which had br ken from it Thi pie e later moved out into the Arctic Ocean to bec me a floating ice i land Other large por ti n are mi ing fr m the helf ince it was fir t i ited by G S Nare in 18 5 and R E Peary in 1906

The ice i land prob ably break from the helf during year of generally warm Arctic climate uch a the period 1900 1930 The age r period of growth of the land fa t ice along the e hore into ice as thick a the ice i land can be mea ured in hundred of years and depend on the general climati condition

F g 1 U S A Fo ce photog aph of Ice I la d T-3 (Offic of photograph USAF Camb dge R ea ch C te Ma



F g 2 Drift of Fletcher s Ice Island T-3 d ing ts per od of occ pancy (USAF Camb idge Research C ter Mass)

Scientific endeavor In March 195 a landing was made on one of these i lands, designated T-3 (T for radar target) or Fletcher Ice I land for C I J O Fletcher who wa in charge of the first operation there Thi i land wa ccupied from March 1952 to May 1954 April 1955 to Septem ber 1955 and continually ince April 195 In 1952 a landing was al o made on T 1 the first i land di covered and large t of the known ice i land but no permanent facilitie were in talled In 1955 the USSR located ne of it N rth Pole tati n on what i evidently one f these i land

The ice island are excellent platform for Arctic scientific tudie Once away fr m the land area the i land are move l at peed up to 5 mile per day by the wind in an erratic cour se that takes them clockwi e around the Arctic ba in from Elle mere I lan l toward the ea north of Ala ka and ea tern Siberia and fr m there toward the P le (Fig 2) From thi area they may mo e ba k t Elle mere f rming a ir ular p th f m 000 or 3000 mile which i ered in al t 15 year or they may m ve fr m the polar area th t of th Ar tic O ean by in by way f th Greenland Sea in which ca e they w uld ontin e th and e entually di int grate The camp at Fl t her I I land r u ed exten i l f r Arct t d n meteor l gy ocean grapl gra ity geo n gn t s t n ph ric and a r ra [illegible]

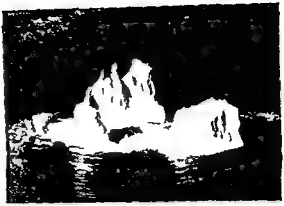
P I I graph H Land berg (ed) *Ad a* *G ophy* s 1 3 195 I S K nig K R t er awa M Dunbar and G Hatter l y Smith Ar t *ice i land* 4 t c 5 6 10 19

Ice manufacture

Commer ial prod ti n of artif i l i from w t or dry i e from the ol l f ati n of arl n l i l (see Dry ice) by mechan al refrigerat Of

glac i th J c b havn Gla er at l titude 68 N cal ng ab t 1 400 berg yea ly and the large t i th Humboldt Gl c r at lat t de 9 with a e ward fr nt = tend ng 65 mil = The emaind r of th Arct c be g er p ome fr m East Greenland a d the i land eecap f Ellesm re I l nd Icel d Sp tzberg n, nd No a Zemly w th almo t n siz ble b rg p duced al ng the E r ia or Ala ka Arct c oa t No ic b rgs a d cha ged o d it into th N th P fic Oc n r ts adjacent as e c pt few small be gs ca h y a th t cal e from th piedmo t glaci rs al ng the G lf of Al ka The e h e e no gn fic nt dr ft S e ARCTIC OCEAN ATLANTIC OCEAN

O ean u rents f the Ar t c and adjac nt as d t min th d ft d lumate d tribution of ceb rg d ha g l ttle ffe t ex ept on sm ll a l haped fr gm ts The dom na t d ft long th Ea t G e la d c a t thwa d ar d the tip f G l nd and th n n thw rd al n the t c t He e th drift ng b rgs j in the main body of West G ee l d b rg nd d ft in a o n t r lockwi g al ac s D vis St a t and Baffi B y Th berg re th pt so thwa d al g the co t f Baffin I land Lab ado nd N wf nd land by the Lab ador C r t Th drift term t al g th Gr nd Ba ks of N wf ndland here th w te of the Lal ad r C rr t mix th the w m Gulf St am nd e e th larg t of b rg melt th n t o t three week Fre k icebe g d ft h v been r p ted wh e be gs r r m ng f agme t were hted off Scotland N a Scoti B muda a d v n the A s I la d Su h re p t h m ext m ly r e Ab t 400 berg e h y r a e c rr ed pa t Newfo ndland as



Fg 2 A ctc c b g 8 g has b d d t fo m v lley dry-dock typ Su h gr t q e sh p mm to th gl c olly p od c d ebe g f th N rth N t th b sh d sm ll floe f c s r d g th be g

s rvivor of the timated 3-year journ y fr m We t Gree land The emainder b come strand d along A ctic c ts d sh als and are ultimately de t yed by wave rosi and mmer m lting

Iceb g in th N rthern Hemi ph rarely reach propo ti ns l rger than 2000 ft i breadth or 400 ft in height bo e th water (F g 2) H w e er tr e gl c l ice i lands e al mil s in extent a e occ nally f und and ha e even erved a flo t ba e for scient fic tudies The rigin of these ra cou terpart of the ommon Antarctic type is u ce t i but th ght t be an ice h lf al ng northern Ellesmer Island S ICE ISLAND

Antarctic icebergs I the Southern Ocean bergs or g nat f om the giant ice h lves all along th

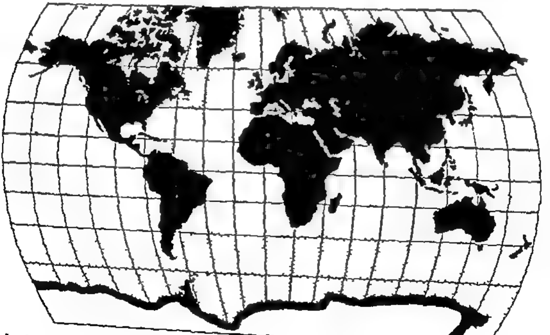


Fig 1 N mol f f b g d ft

Ice is also frozen artificially in a flat horizontal sheet for ice skating. Such skating rinks may be indoor or outdoor, permanent or portable. The rink floor is covered with pipe coils through which cold brine is circulated and over which water is sprayed until a frozen sheet ½–¾ in. thick is obtained. The brine is cooled in brine coolers by a refrigerant such as ammonia or Freon 12. *See* REFRIGERATION.

[H. M. HE.]

Bibliography: American Society of Heating, Refrigerating and Air Conditioning Engineers, *ASRE Air Conditioning and Refrigerating Data Book*, 1956–1959.

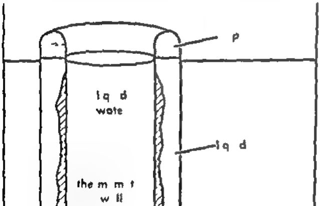
Ice point

The temperature at which liquid and solid water are in equilibrium under atmospheric pressure. The ice point is by far the most important "fixed point" for defining temperature scales and for calibrating thermometers (*see* TEMPERATURE). A closely related point is the triple point, where liquid, solid, and gaseous water are in equilibrium. It is 0.01° higher on the Kelvin scale than the ice point (*see* TRIPLE POINT). The triple point has gained favor as the primary standard since it can be attained with great accuracy in a simple closed vessel isolated from the atmosphere. Readings are reproducible to about 0.0001 K, but dissolved gases or other foreign matter may raise the error to 0.001° or more.

The triple point apparatus shown in the figure consists of a thermometer well that is filled with liquid water and jacketed by a cavity containing the three phases of water under a pressure of about 0.006 atmosphere. The ice, initially deposited by prechilling the well, melts during the process of heat transfer from the thermometer.

[R. A. BL.]

Bibliography: H. C. Wolfe (ed.), *Temperature: Its Measurement and Control in Science and Industry*, vol. 2, 1955.



Arrangement for determining triple point.

Iceberg

A large mass of glacial ice broken off and drifted from parent glaciers or ice shelves along polar seas. Icebergs should be distinguished from polar pack ice, which is sea ice, or frozen sea water, though rafted or hummocked fragments of the latter may resemble small bergs. *See* GLACIER; SEA ICE.

Characteristics and types. The continental or island icecaps of both Arctic and Antarctic regions produce icebergs where the icecaps extend to the sea in the form of glaciers or ice shelves. The "calving" of a large iceberg is one of nature's greatest spectacles if one considers that a Greenland berg may weigh over 1,000,000 tons and Antarctic bergs are many times larger. The glacial ice of which an iceberg consists is compressed snow having a variable specific gravity which averages about 0.89. This results in an above-water mass of from one-eighth to one-seventh of the entire mass. However, spires and peaks of an eroded or weathered berg will result in height to depth ratios of between 1–6 and 1–3. Tritium age experiments with melted Greenland berg ice indicate these bergs may be of the order of 50,000 years old. Minute air bubbles imprisoned in glacial ice impart to bergs a snow-white color and cause it to effervesce when immersed. *See* SEA WATER; TRITIUM.

Icebergs are classified by shape and size. The terms used are arched, blocky, domed, pinnacled, tabular, valley, and weathered for berg descriptions, and bergy bit and growler for berg fragments ranging smaller than cottage size above water. The life span of an iceberg may be indefinite while the berg remains in cold polar waters, eroding only slightly during summer months. But under the influence of ocean currents an iceberg that drifts into warmer water will disintegrate rapidly, its life being measured in weeks in sea temperatures between 40–50°F and in days in sea temperatures over 50°F. A notable feature of icebergs is their long and distant drift, which may carry them into steamship tracks, where they become hazards to navigation. The normal extent of iceberg drift is shown by the accompanying world chart (Fig. 1).

Arctic icebergs. In the Arctic, icebergs originate chiefly from glaciers along Greenland coasts. It is estimated that a total of about 16,000 bergs are calved annually in the Northern Hemisphere, of which over 90% are of Greenland origin. But only about half of these have a size or source location to enable them to achieve any significant drift. The majority of the latter stem from some 20 glaciers along the west coast of Greenland between the 65th and 80th parallels of latitude. The most productive

Ichthyosauria

F h l ard th m t highly ad pt d f all r pt les to l fe in the sea W ll p rved f l h w th e t re body form th a ampre ions of tail fl k paddles d r al fin e n of bry c k l t s l ed up w th tl m ther s body ready wh n bo n t w m n the p n n the m ner of y u g wh les A p men h s b n rec red n hich b rth wa o rr ng t th t me f th m th r d th wh h h ws th t th eml ryo ere not y ng hthyos u s wh h t had all wed fo f d

F rly hthy a r h d l g to the d fi h at h m ja imil r to the g p k a d gavial Som h d bl nt t th f cr h h ll fi t Lat Creta us form l t the teeth and had b k like tl o f th d fi hes and m rl s wh ch they eaily mbl d All we pred ceo s and m l rger n p b bl f d th r i l thy u The arl est had t g fl t d te th t sock ts L t r the socket ra t tl e int groo e and till l ter the t th be am mall and l elv t Th ey wa e pt all l rge t e k prey in mod r t ly deep w t

In a ly g n a the el ng te ta l wa turn d d w tow d tl e t p wh it w s p n l d i t n rr w el t fin Lat n th Jura i th ta l be ho t d wa t n d abruptly d w at th t p f th t al upp rt f n la ged t m n l fi Thi t il fin wa th m i pr pul e rg n whi h tr n mitted t gre t f e th h th br ad fl t e t b a f tl b y p nal l mn V rt b r t 200 mb we e d l ped mu h s n h le

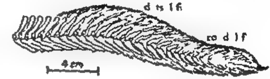
The pa d fi s o paddl d r d f om th fe t fl l t a d f tw ma typ br d d a r w u d a udd nd elevat de- pr when th c t t th u fa t b e th o bme ged to f ed Th r wa al a t l l g d l fi without pp rt n kelet n wh les a d hark t p e t d l p whil w mm g Th tri t al with th enti ut l f th b d i p e rved th ma kabl f l f nd t nd tly at H lzmaden (m ny 60 ft Th gi nt f m of the Lat T i d E ly Ju a i the l rg t a m ls f th r day th l t p tat f th l ng t l d f m d w r ne ded by mall p b bly

A J c chthy sau m h ed d (S mpl f ed f m E St m d by A S R m V rt b at P l t l gy Th U ty f Ch g P ss 2d ed 1945)

m re act h rt ta led type T thless f rms late in the Cretaceo s r pidly decrea ed in numb er nd ext nction to k pl ce l ef re tl e cl e of the Creta eous wh n th ichthyo aurs w re evidently upplanted l y th mo a ur of the order Squa mata ubcla s Lep do u m See LEPIDO AURIA SQUAMATA [C L CA]

Ichthyostegalia

A gr p f labyri th d nt mph bia found in Late Devon an depo t in Ea t Greenland and hence the old t r pr entati e f th class known at



T l of I hthy st g o c t ol l by th do t am ph bi h w ng fi ays et e f m f h o c to (F m E H Colb rt E l to f the V rt b t W l y 1955)

p e ent Th limb and g rdles ar of an amph bian p tt lth gh mall a d p i niti e in tru ture but th e i a defi it f edu ed caudal fin remi n ent of pi e ne ance tor Th ertebr e a e comparabl t tho e of cr pterygian fi he n th ne hand nd rha h t m us amph l an on th the The skull pp rs t b p cial d i g e ter d ct n of the oti notch than would l e exp t d in truly an tral amphibi n and the int rtemporal b ne i ab nt Th k ill is r mark l ly p im t ve th r f t r pa t e larly n the t t of a la ge canal f r the n t chord through th ba f the occipital reg on th s con tru t on ch r cte i ti of cro sopt ryg ans is ab- se t n all lat amphib ns S e AMPHIBIA FOS- SILS LABYRINTHODONTI RHACHITO I see also CROSSOPTERYGII [A S R]

Ictidosauria

A few extrem ly mammal l ke rept l (ub l s Synap d) ar gr up d nde the ord r Ictido- a ria S e tl l d d ge e a p obably temmed from mo e than a gl u e among th th ap d pt l ynod nt d the cepha l th d p b bly i phylogen ti ally rti fi al Altho gh e y l e t mammals ict d s rs a e techni lly exclud d by tl pt li n natu e of th l wer j w and m d lle e r ll p nt ti e o c r n the upp rmo t T ia s c (probably] Low J r c) depo its On group the tritylo- d t s k own fr North Ame c A a E r pe nd South Afri Ict d aur p op r are known f m South Afr a ly All i tid au we e mall a imal o m r than 3 ft i length The g pi lud d both a n or a d h rb r and eem t hs be n t ted to t re tr al l fe The rep e t n of the s u es f mammal S SY APSI A THERAP IDA [E C O]

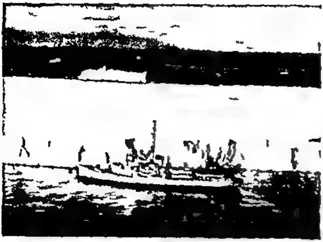


Fig 3 Antarctic iceberg Tabular type berg or ice island is common to all regions of the Antarctic seas Some of these bergs may reach over 100 miles in length The U S Coast Guard Icebreaker *Westwind* is shown in the foreground

Antarctic continent These result in huge tabular bergs (Fig 3) or ice islands several hundred feet high and often over a hundred miles in length which frequent the entire waters of the Antarctic seas The most active iceberg producing region are the Ross and Filchener ice shelves in the Ross and Weddel seas The large size of these bergs and influence of the *Antarctic Circumpolar Current* give them an indeterminate life span When weathered Antarctic icebergs attain a deep bluish hue of great beauty rarely seen in the Arctic *See* ANTARCTIC OCEAN [R P DI]

Ichneumon

Any member of the insect family Ichneumonidae order Hymenoptera Although they are frequently called *ichneumon flies* these are actually wasps (*see* WASP) The ichneumons are a widely distributed and highly successful family There are over 6000 species in North America They are parasitic insects as larvae the female deposits her

The long tailed ichneumon *Megarhyssa* lunator (an ichneumon fly) length female to $1\frac{3}{4}$ in (From E L Palmer *Fieldbook of Natural History* McGraw Hill 1949)

eggs within the body of the insect or spider host by means of her ovipositor which is frequently the most prominent part of her body The greatly developed ovipositor of some of the ichneumons as much as 6 in long on one species frequently cause people to be frightened by these harmless insects They are beneficial in *helping control very populations* of harmful insects Virtually every known species of insect is attacked by some species of ichneumon *See* HYMENOPTERA [J D B]

Ichthyopterygia

Predatory fish finned and sea swimming reptiles of the Mesozoic Era widely divergent from land forms although surely descended from some ancient terrestrial group as yet unrecognized All are much alike in body form short necked streamlined swordfishlike or porpoiselike in body yet unrelated to either fishes or porpoises a noteworthy example of convergence in evolution A single order is included in this subclass *See* ICHTHYOSAURIA [C L C S]

Ichthyornis

A genus of fossil bird of Late Cretaceous age known from six species from the Niobrara formation of western Kansas and one species from similar beds in Texas These form the family Ichthyornithidae and with the related *Apatornis celer* (Marsh) family Apatornithidae the order Ichthyornithiformes (subclass Neornithes) They differ from all other birds except the Archaeornithes in having the centra of the dorsal vertebrae with each end concave (amphicoelous) *Ichthyornis* and *Apatornis* were pigeon sized flying birds with well developed wings and keeled breastbone When first described by O Marsh parts of jaws bearing teeth in sockets were associated with the other bones so *that for many years they were known as toothed* birds In 1952 however J T Gregory from studies of the original material in the Peabody Museum Yale University found that the jaw fragments were not as an but were from reptilian mosasaurs *See* ARCHAEORNITHES AVES AVES FOSSIL ICHTHYORNITHES NEORNITHES [A W]

Ichthyornithes

One of the three superorders comprising the subclass Neornithes or true birds The two families that make it up were until recently placed in an order Ichthyornithiformes in the superorder Odontognathae in the belief that *Ichthyornis* possessed teeth J T Gregory showed that the toothed jaw long assigned to *Ichthyornis* was reptilian probably that of a mosasaur This removed the principal basis for placing *Ichthyornis* near the toothed *Hesperornis* However *Ichthyornis* differs from later birds in possessing biconcave vertebrae which set it apart at the superordinal level The eight known species of Ichthyornithes are all from the Upper Cretaceous of Kansas and Alberta and Texas They were flying birds of island and gull like in their proportion *See* AVES NEORNITHES [K C P]

gr wn rap dly but imperfectly to form keletal c y tals (F g 1)

I mo t r ck grain shape i ont ll d largely by quence f m neral cry tall zat o and th na tu d ar ety f a sociated m rals A g ain s said t be euhedral f bound d f y its haracte i tic cryst l f es and nhedral f cry tal faces re ab- se t. Interm d ate forms ar ubhed al Cr tal developed e rly i a magma te d t be euhed al Late crystal h weve m et nterf ence f m n me o s adjace t gra ns and re for ed to a um rregular m tual bo nd r es

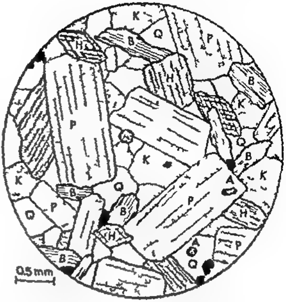
It i not nec s ary that all mutu lly int rfering g n de elop anhedral f rm S me min ral spe e po s a gr at power f gr wth (a gr ate form ene gy) and re capable f ma ntaining th r hara t ri t c ry tal form in c mpet t on w th d f ent m ne als

M t gneou r ks how a g ainy or granular te t re n whi h th maj rity f cry tal are oughly equ d men onal Ra ely g ains with e he- d l oth e d m nate and g e th rock an id o- m ph c gr ular t xtu e M r c mmonly n arly all g a n a e anhed al and the rock texture i allotri m rph nula M t r ks how an in t m diate o typ d om phic g anul texture (F g 2)

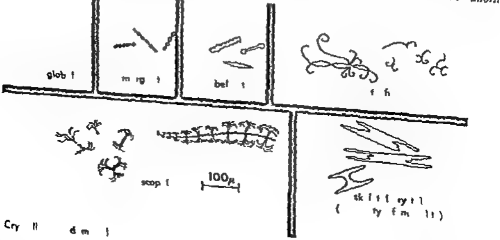
Po phyriti te tu e The grai ze of s me gne- ou ock i extrem ly un form (eg granula tex tu e) but that of th r may be h ghl in qu g an ular Rock n wh ch rel t ly large cry tals (phe- nocry t) a e d sp rs d n a matri gr undma s of fin r g a ed gl s y m t r al a said t be porphy t r phyr c (F g 3) Po phy ti gla es th abu d nt ph n ry ts r k wn spec fi lly a it phy

P rphyriti ock m y form in numb r f way (1) Phe ocry t m y h g wn arly and l wly hile the m gma was d ply i ur ed The gr und m may h ong led lat ft r th m gma w rupted t h ghe le l wh r a d co li g d ( ) Ph cry t n many ocks (me g n t) m y de l p i te a d t ll atta n l g d men on if thei g owth ate i s ffici ntly *gr ter than that of* adjacent mine al (3) The la g ry tal of s me plutonic ro k *are p obably* mo p op erly l ed as p rphyr bla ts They m y h e formed es e t lly in lid rock by recry tal lizat n a ded by re du l flu ds from the ol di fying m agma (4) La ge cry tal in many rocks (e ta n p rphyri s and lamprophyres) *may n t be* indigenou They may h ve b en incorporated du ing intrus on f the magma (5) Ph no ry t m gl t d vel p by in culation or by di tu b nce f uper tu ted m gm *S e* LAMPROPHYRE PHENO- CRYST POR HYRY

P kilit c t tu Th t ture nvol es numerous m ll g in f on m n ral i r nd m or ent tio ncl ed by ingl la ge c y t ls of anoth r



Fg 2 Hyp d omorph c g l text e n g o od o t Euh d of pl g o la (P) ubh d ol ho nd (H) b t te (B) hed l q tz (Q) and pot sh f ld pa (K) A s ry m ls l cl de h d l ap t t (A) d bhed l m g t t (blo k)



Fg 1 Cry ll d m l

Idocrase

A orosilicate mineral of complex compo ition crystallizing in the tetragonal system al o known by the name vesuvianite Cry tal frequently well formed are usually prismatic with pyramidal terminations It commonly occurs in columnar ag gregates but may be granular or massive The luster is vitreous to resinous the color is usually green or brown but may be yellow blue or red Hardness is 6½ on Mohs scale specific gravity is 3 35–3 45 *See* SILICATE MINERALS

P mat c crystals of m neral docrase showing pyram idal te m atio s (From C S H rlbut Jr Da a s Ma ual of M alogy 16th ed W ley 1952)

The composition of idocrase is expres ed by the formula $Ca_{10}Al$ (Mg Fe) Si O $_4(OH)_4$ Magne sium and ferrous iron are present in varying amounts and boron or fluorine is found in some varieties Beryllium has been reported in mall amounts

Idocra e is found characteristically in crystal line limestones resulting from contact metamor phism It is there associated with other contact minerals such as garnet diop ide wollastonite and tourmaline Noted localities are Zermatt Switzerland Christiansand Norway River Vilui Siberia and Chiapas Mexico In the United States it is found at Sanford Maine Franklin New Jer ey Amity New York and at many contact metamorphic depo its in western state A compact green variety resembling jade is found in California and is called californite [C S HU]

Igneous rocks

Tho e rocks which have congealed from a molten mas They may be composed of cry tals gla or both depending on the conditions of formation The molten matter from which they come i called magma where erupted to the surface it is com monly known as lava Solidification of the h t r ck melt occurs in re pon e to lo s of heat Generated at depth the magma tends to ri e It commonly breaks through the earth s crust and spill out on the earth s urface or ocean fl or to f rm volcanic or extrusi e rocks At the surface where cooling i rapid fine grained or gla sy rocks are forme l

Where unable to reach the surface magma cool more sl wly m ulated by the o erlying rocks and a coar er texture de el ps The re ulting igneou rock appear intrusive relati e to adjacent rock In general deeply f rmed (plutonic) rocks di play the coar est texture Igneous rocks formed at hal low depths (hypaby sal) display features ome what intermediate between those of volcanic and plutonic types *See* MAGMA PLUTON VOLCANO VOLCANOLOGY

Textures of igneous rocks Texture refers to the mutual relation of the rock constituents within a uniform aggregate It is dependent upon the rela tive amounts of crystalline and amorphous (gla y) matter as well as the size hape and arrangement of the constituents

Rock textures are highly significant they hed light on the problem of rock gene is and tell much about the conditions and environment under which the rock formed

Crystallinity This property expresses the pro portion of crystalline to amorphous material in an igneous rock Most igneous rocks uch as granite are compo ed entirely of cry talline material and are called holocrystalline Entirely glassy or holo hyaline rocks such as obsidian are extremely rare Many rocks such as rhyolite or vitrophyre contain both glass and crystals and are called hypocry tal line or hypohyaline

Glass may be considered an amorphou oli l with no systematic arrangement of its con tituent atoms Crystals form as the temperature of a magma falls and atoms begin to arrange them el e into orderly repetitive group With rapid cooling there may be no opportunity for cry tal to de el p and a magma will congeal a glas

Granularity or grain size In igneous rock grain size ranges widely and depend in large part upon rate of cooling Rocks are phaneric or phanero cry talline if their constituent mineral grain can be distinguished as individual entitie by the naked eye All other igneous rocks are aphanitic

Phaneritic rocks are divided according to a er age grain diameter as follows fine grained grains le s than 1 mm medium grained grain 1 5 mm coar e grained grain 5–30 mm very coar e grained (pegmatitic) grains more than 3 cm

Aphanitic rocks are microcry talline if indi i l ual c nstituents can be di tingui he l only with th micro cope They are cryptocry talline if n tit uent are sul micr copically ry talline D mi nantly gla y rock are con ider d aphanitic Aph anitic rock rich in light col red (fel i) mineral are termed fel itic *See* FELSITE

Grain shape In igne us rock grain hap i n tr lled by many fact r In highly gla y r k th rate of gr wth i imp rtant Cry tallit (Fig 1) are the mo t rudimentary f rm an l al un l in gla sy rock in which rapi l n li lati n l r te ted f rth er growth They are t o mall t y lar ize light and cannot l id ntif e l a t m r l specie The e embryonic f rm ar i rthat n t aried an l beautif illy di p l ye l in th gl k pitch t ne *Se* OBSIDIAN

Micr lite are slightly larg r el ngat ry t l They p lariz light and can u ally l i l ntif l specifi ally un l r th micr ope Many l a

gr n rap dly b t imp rf ctly to form keletal cry tal (Fig 1)

I most rocks, g ain hape cont lled larg ly by quen of m neral crystallizat on nd the a t r and a ty f a soc ted mi ral A grain i sa d t be e hed al f bounded by it el aract t c ryst l faces and nhedral if cry tal f es are ab- se t. Intermedi te forms ar subhedral Crystals dev loped early in a magma t nd to be euh dral Lat ry t l h we er meet nt rfer nce f om n m ous adjac nt gra s and are forced to a sum irr gula mutu l bo ndaries

It i not neces ry that all m tually inte feri g gr n de elop a hed l form Some mi eral pe- c s po e s a greater p wer of owth (great r fo m ene gy) and are apabl f m int in ng the r har cte i ti cry tal form competiti n w il ad j ce t m e al

Mo t igneous ocks how a ny o g anular t tu m h ct the m jor ty f ry t ls are roughly equid me ional Ra ely g a ns will e he d al o th e d m nate nd g th rock an idio- m rphi granul r textu e M r mmonly nearly all gra n are anhed al and the ock texture i all tri m rphi g anul r Mo t r cks how an in t rmediate or hyp d omorph c g nular te tur (Fig 2)

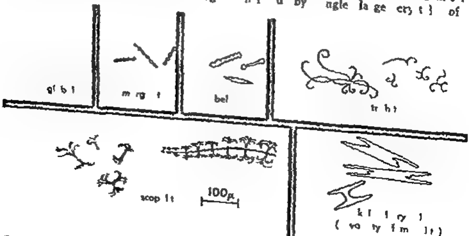
Po phy it c textu e Th gr n e e f om igne- rocks s extr mely un form (equ gr nular tex t e) but that of the may be h ghly inequ gran ul r R ck in wh ch r lati ly large rystals (phe- nocry t) ar d p r ed in m tr x ground n ss f fi r g a ed r gl ssy materi l ar id t b po phy ti ph c (F g 3) P rphy t c glas es th b dant ph ryst ar kn spec fi ally a tr phyres

P rph it t r m y f rr r a umber of ways (1) Ph oc y ts m y b gr wn arly a d lowly h le th magma wa de pl b ited The g u d ma m y ha e g aled lat r aft r th m gm w rupted t h ghe le l whe apid cool n en ed ( ) Phenocry s many ock (som gran t) m y d el p lat and st ll attain l rg

Fg 2 *Hyp d morph c g a ul t t g o od o- t Euh d al pl g cl s (P) bhed al ho nbl de (H b t t (B) hed l q rtz (Q) d pota h feld pa (K) Ac e ory m e ls l d h d al p t t (A) d ubhed l mag et t* (bla k)

dimen ons if the r growth rate i sufficiently gr at r than that of adj c nt m ne al (3) The large ry t ls of s me pluton c rock are probably more prope ly la ed as po phy obla ts They may ha e formed s nt ally in ol d rock by re ry t l lizat on a ded by r id al fl id from the lid fyin magma. (4) Large ry tal in m ny rocks (rta n p rphy ies nd l mp ophyres) may not b indigen s They may ha e be n inco po ted du ing trusion f th m gma (5) Ph no ry ts m ight de el p by no ul ti or by d t b nce of per sat ated magma S LAMPROPHYRE PHENO CRYST PORPHYRY

Po k l tic text Thi text e invol numerous mall g ains of one m neral in and m o i ntat n l d by ngle la ge cry t l of another



Fg 1 Cry t l d m t

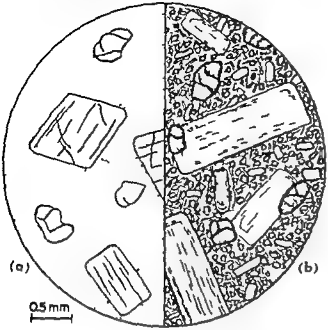


Fig 3 Porphy it te tu es (a) Porphyr t c rhyol t how g euh d al phenocrysts of san d e and e so bed crystals of qua tz in a bmic o copically crys tall e matr x (b) Po phyrit c basalt showing euhedral phe ocrysts of plag oclase d subhed al ol ne a mat x of g anular py e e and feldspa m c ol tes

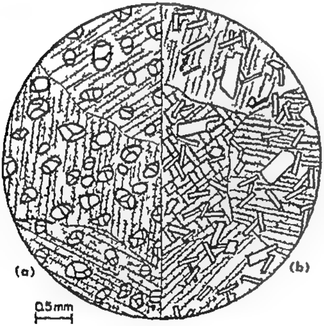


Fig 4 (a) Po k l t c te t re w th l rg crystal of h nbl de enclo g ob d t small g ains of ol v e (b) Oph t c t tu e w th l rge cryst ls of py o e en cl g small l th of plagiocla

(Fig 4a) Conditi n fa ring de el pm nt f p i kilitic t xture are n t well under to d In ome rock th texture may have de el ped by direct cry tallizati n f magma In oth r r ck thi tex tur may repre nt recry tallizati n of magmatic rock

Ophitic texture Thi a pecial type of poikili ti t xture an l hara teri tic of th rock diabase (Fig 4b) Th texture inv lve lath haped crystal of plagiocla e feld par enclo ed by large anhedral grain or plates of pyroxene (augite or pigeonite) If the length of the feld par cry tal exceed that of the pyroxene enclo ure i only partial and the tex ture i called ubophitic *See* DIABASE

Other texture more or le related to ophitic *are characteri tic of very fine-grained and gla y* rock of basaltic compo ition *See* BASALT

Implication or intergrowth textures The e are formed by the mutual penetration of two or more mineral pha e The intergrowth may be so inti mate that one pha e appear di integrated into smaller grains which are i olated by the other Within mall domains however grain of one pha e show optical and cry tallographic c ntinuity

Graphic or micrographic textures may develop between almo t any mineral pair where one mem ber in cuneif rm ma e re embling runic in crip tion i enclo ed by the other (Fig 5a) Micro-pegmatitic texture is e entially a micrographic texture involving only quartz and p ta h feld par (Fig 5b) If the intergrowth i more varied and invol es plumo e fringing radial or micr peg matitic pattern the texture i granophyric (Fig 5c) In myrmekitic texture plagi cla e (gen erally oligocla e) grains enclo e vermicular quartz (Fig 5d) Perthitic texture i extremely comm n in feld par and take on a wide variety of form (Fig 6) It u ually con i t of tiny ma f s lic plagiocla e enclo ed by pota h feld par Vari u pr p rtion of the two con tituent may exi t Where pota h feld par i more abundant and c n titute the ho t mineral the material i kn wn a perthite Where plagi la e pred minate the material is called antiperthite

Some implication textures may develop by simul tane us cry tallization of two c n tituent Other may f rm by ex oluti n in the olid tate (s me perthite) Still other texture may be d e to the partial replacement of one mineral pha e by an other

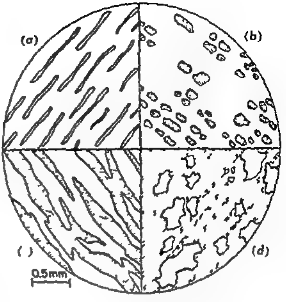
Structures of igneous rocks Structure as ap plied to igne u rock i a ily confu ed with tex ture In gen ral howev r tructure r fer t a g metrical f rm or ar hitectural fe ture in a r ck Stru ture empha ize the heterogene u nature of *a ro k or mineral aggregate texture empha iz* homogeneity C rtain larg ale tru tur u h a fault f ld and j int are mm t mo t rock type They are perhap m r pr p rly cla e l a geol gic tructur Like textur the truct re of igneou r ck may tell m h al ut th hi t ry r nditi ns of f rmati n f th r k them elve

V sicular structures The structur ar n m n in many lcanic r ck They f rm wh n m gma i brought to or n ar the earth rfa H re the l w pre ure p rmit partial r l a and xp n i n f h l l water r th r v latil and th f rmati n of team bubbl which may b pre erved a mall cavities wh n th m gma ng l In h gh ly vi cou la a (rh y lit) m h ga may b trapped b t nly tiny bubbl may f rm Rapid

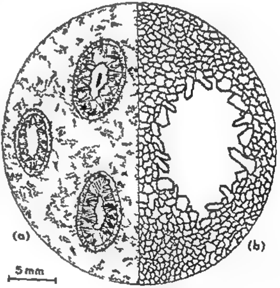
ool g f th f thy l quid p od s a pum ceo s tru t re (h a ter tic f th r k pum c) In le c la a (ba altu) nt gratı of tı y bubl l p od es a c ar er p ngv o co ı ceo tr cture (cha acte ı tı f th ock or a) Ve- l t on f s m ba lt c la s pr du e well f rmed ell pso dal ▪ ıtı Th ▪ may later l fill d th m eral (u h a qua tz, cal ıte ep d t eol t) dep ted fr m fl ıd wh ch p m ted th rock Such fill ng re called amygdul s ı llu to th ı lm d h pe Th tru t e ıs k wn a mygdal d l (F g 7a)

M a ol t ope ıng Th ar the m st omm n ca n u tructu fou d n pluton c rock They a e *rr* gular ▪ ge up to several ın he a nd app ar cru t d w th beaut fully fo m d c y tal (q rtz a d feld par) The c y t l are n t truly r t g a a ty w ll th b es co t t t a teg al part f the o k (Fıg 7*b*) Th s fa t d tes that a h a ıv (vug) f med a a m ll ı t r p c n the cry tal aggr gate a d filled with res d l magr atıc fl d aga n t wh ch bou d g g d ly de l ped tl ı uhed l th e Th pres c f m te tourm l ne top z, and ap t te g t th t l t l (wate flu ı and bor n) wh h ▪ t t n e ıdu l m gm t fl ıd l pl yed a mp rta t ole ın th devel p m t f m lt t u tu Th a ıt ar mo t f k ly t f m ın ks c y tall z ng t hall w d pth whe f g pres s latı ly low

Z d y r ls C y tals p s ng zon l st t ▪ ▪ comm n a d pp a to be b lt up f co trı hell r es f d ffe ent mp s t n *wh h f ll* w the g af ry t l outl n (F g 8) Th gh m nute thes z n l tr t es a eadıly d t ı d th n ct ▪ und th m c o c p l d d al e may b th k or th nd z ed



Fg 6 P rth ı t t ( ) St g p rth ı (b) P t h p rth ı ( ) V perth t (d) A t p rthıt



Fg 7 ( ) Amygd lo d l t t h w g f m ga t (b bbl) l fill d w th l t m als (b) M ı t ty f e-g d g a t w th all t o- m ph g lo t t E h d al tl bl ly wh ryst l f m ty b d y

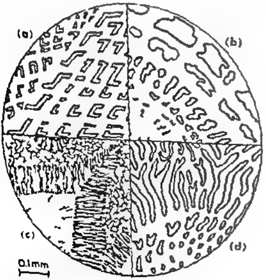
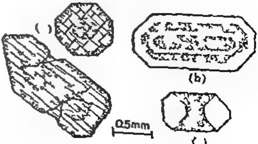


Fig 5 Impl t g w t t ( ) M o- g phic t t (b) M opegm tı te t ( ) G o- phy ıc tı (d) Myrm k t t t



Fg 8 ( ) Z d ry t l f py plog cl ( ) H gl t ct py (b) Z ed

boundaries may be harp or gradational Composi tional changes from the cry tal s center outward may be great or slight they may be progressive rever ed interrupted o cillatory or repetitive Zoning i characteri tic of minerals belonging to olid olution eries (for example plagiocla e pyroxene and amphibole)

Numerous theorie have been propo ed to explain various types of zoning in minerals The e are ba ed on physical chemi al principles relating to super aturation of the magma and changes in com po ition pressure temperature and volatile con tent of the magma Movement of crystals from one part of the magma chamber to another may have been important The mo t common type of zoning (progre ive) appears becau e of incomplete re action between solid and liquid pha es during the crystallization of an i omorphous eries

Hourglass structure This structure omewhat related to zoning is mo t frequently di played by cry tals of pyroxene Certain ections through a cry tal possessing the tructure have the appear ance of an hourgla s (Fig 8) This tructure probably demon trates the minute differences in energy invol ed in different faces of a growing crystal It may be due to electi e ad orption of ions by dif ferent face during crystal growth

Reaction rims The e rims or zone in which one mineral envelopes another are l elieved to have formed by reaction and are common in some rocks (Fig 9) They may develop by reaction l etween early formed crystals and surrounding magma

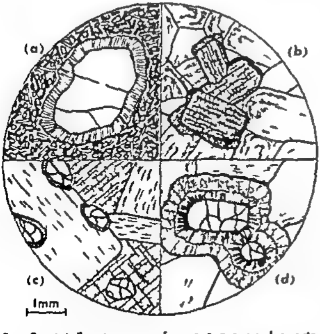


Fig 9 ( ) React o m of py o e e a ou d q artz g a basalt (b) React on m of ho ble d a o nd th ee g ns of a thopy e e o te Mo t of ock is composed of plag oclase (c) R act on m of o tho pyro e fo m d betwe mall ol i g a s a d plag ocla e d base No m e sts b tw en ol e i o te (d) React o ims o u d ol i o ite l e m f o th py o e o te r m of amph bol

(pyroxene rims on early formed olivine cry tal) Reaction betv een two incompatible mineral in duced by re idual fluids in the late tage of magma con olidation may produce similar effects Pyrox ene or amphibole may form l y reaction around olivine cry tals where they would otherwi e come in contact with plagiocla e Some petrologi t re fer to rims of primary origin as coronas and tho e of econdary origin as kelyphitic borders

Spherulites The e are radial aggregates of needlelike cry tals They are roughly spherical and u ually le s than a centimeter across (Fig 10) They abound in ilica rich lava particularly rhyolitic gla s and are compo ed principally of quartz, tridymite and alkali feld par

Somewhat similar aggregates in ba altic rock called variole con ist of radial plagiocla e cry tals with interstitial gla s or granules of olivine or pyroxene

Spherulite consisting of concentric hell with cavernous inter pace are known as lithophy ae or stone bubl le In many the tiny annular cavitie are lined with delicate cry tals of cri tobalite quartz and feldspar

Inclusions or enclosures Inclu i ns are comm n in most varieties of igneous rock The e ma es of extraneou looking material vary widely in size shape con titution and origin Inclu ions demon strated to be foreign rock fragments enclo e l and trapped by congealing magma or lava may l e specifically de ignated as xenoliths Incorporated for eign crystal are known a xenocry ts *See* XENOLITH

If an earlier con olidated portion of a magma i ruptured and fragments of it l ecome enclo ed by portion which olidify later the older rock l o lies are known as autolith Enclosure f rmed by elec tive accretion of mineral either during or after con olidation of a magma are termed egregati n

Orl icular st uctures The e structure found in ome plutonic rocks (granite gran di rite and diorite) are orl lik ma es generally up to a few inches acro They h w concentri shell of dif ferent mineral compo iti n and thickne which may en elope xenolithic core (Fig 11) Mo t comm nly dark mineral shell (rich in l i tite hornblende r pyr xene) alternate with light shell (rich in feld par) In lividual shells may l e sharp ly or aguely defined and the mineral within may l e granular or elongate and in radial r tangential arrangement

Orl icular tr icture may d velop l y reacti n (l tween xenolitl and magma) inv lving l emi al recon tituti n f the s li l fragment r rhyth mic ry tallizati n ar und xen lith Many rl ic ular tructure may repre ent pro lu t f m ta m rphi m and m ta mati m f li l rock S METAMORPHI ROCK METAMORPHI M MET A OMATI M

Ello or llipsoi lal stru tu Thi type of tru ture i a pec iliar feat ire of certain lava fl ws (l a alt spil te) Rock exl il iting thi tru t ir ap p ar to be ompo ed of clo ly pa ked pill w

haped m es up t eral feet r s Indn dual p ll ha e a fine-grai ed rust or margin wh ch arrie bundant I commo ly ar r nged e nc ntr lly with the p llow surfac

The p ll w re o p f ctly fitted t gether as t sugg t th t they we e as embled in a pl t c tat R lat el l ttl matr x cc r and it n ts c m m nl f chert, l me tone hale The cl e a soc t o f p llow l a w th ed m nt ry r ck in agreeme t with the pop l r belief th t th y ar of ubaqueou o igin Pill w lav s ha e b en observed t f rm both n dry land a d n wat r b t the p c o dit n fa r g the r f mati n ar till not ll nd r t od *Se* SPILITE *s e l o* PRECAMBRIAN

Fl w st u tu Th a nongenet term f r a mber f dir ct fe t in ro k Th t u tu e m y be f rmed by fl wage d r ng cry tall zat on f a magma (pr m y fl w st ture) l o t olidifica t n fl w (eco dary) m y de el p similar fea t but the e a e cl s ed as metam rphi m gi

Th tr tur tak the f rm f par ll l st e ks r len es of d ffere t min r l u t xtu es o n may r ult f om parall l a geme t of elo gate pl t min r l (mi h nble d o f ld p r) Sm fl w tru t re o t of ab nda t labby lu r n n l ths in p allel r entat on Fl ge may b xpre ed by fl w l e (l ne t on) r fl las (me foli t o) Th e may b l ght t rt d

Fl d l t t e and flux st tu e The e g n t term a d p e fic lly imply fl wag f la a m gr a (F g 10c)

S hl S hl e g l tr aks p t h l s ha r g m l ble ded o t l nes nd m u g p t m y fe t n l gth

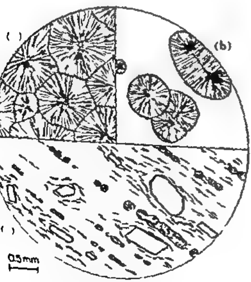
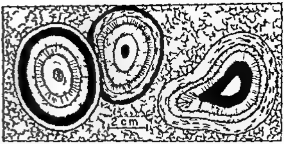


Fig 10 ( ) Sphe l c truct vol pl ( ) Fl d l tru tu (b) Sph rul t l ph l ph ocry ts, m l h w g t of d ry t ll



Fg 11 Ob l t ct

They ar ge erally c mp sed of th ame m n ral s the e clo ng ock but in different proportions Schli ren may repre ent a l se regati n drawn ut by magma fl w Some m y be xe olith more or l d gest d and rew rked by magma Othe s may ep ese t i idual magmati l quors f d fferent c mp t injected into alre dy crystalli ed por tion Schl e en formed n solid r ck are more pr perly met mo phic or meta omatic feature S GRA ITIZATION

Band ng Banding i exhib ted by rocks com ed f altern ting layer f differ nt c mpo ition text re or ol r The term is m r ly de cripti e not g n t c If flow ge i t be impl ed the term fl w b nd n u ed

Classification of igneous rocks Sch mes for la ify ng igne u ock ar numer u Prior to the ad e t f th pol rizing micr pe (roughly 18 0) r k las ficat on re ba ed on mega pi ch ra te st cs many f them m slead ng The yst m w re g du lly imp ed a ch m l analy were more commo ly employed

Today th pr nc pal methods of classificat on a u d (1) M ga c p c ch mes are bas d o th appeara f th r k in hand pec m n as en w th m gn fyi g gl s (hand len) S ch hemes ar ful i th fi ld t dy of ro ks (2) Mic o c pic cheme (la g ly m n alog al) are em pl y d in lab ato y in e t at n wh re more de t led nf m t on is need d (3) Ch m cal sch mes a e e u ful but ha mo e l mited appl cati The m ne al c ntent and t tu e f a r ck g nerally t ll m ch mo abo t the o k s r gin tha d a b lk h mic l naly F xampl gran te q rtz p phyry rhy l te and ob d n m y all h v th ame he al comp tion t the ge lo c con d t s u d wh ch ch f m may be ry diffe ent Gran t sol d fies l wly at d pth a d u der h gh p e u e The po ph yry may rystall n tw stages ne at d pth a d a l t nearer the s r fa e The oth tw o ks a e f u fic al o g n th l d olid fi s most p dly nd a glass

Igneou ck l w gr t a t n hem ally min l g ally textu ally nd t u t ally w th few if any nat al b und es Th c unts i l g pa t f th g at di agr m nt m g petrol g t t l w igneou r ks h uld b cla sified d hyp by l typ plutonic l

Pl t c r cks Pluton c rock n larg n tru m (bath l ths stock a d other l ge

plutons.) They form at great depth and therefore are often referred to as abyssal rocks. Generated from large bodies of magma which has cooled slowly, they characteristically show a phaneritic holocrystalline texture.

Under deep-seated conditions where confining pressure is high, volatiles dissolved in the magma are retained until the last stage of crystallization. These act as fluxes and reduce the temperature of crystallization. Consequently plutonic rocks, as compared with volcanic rocks, may carry relatively low-temperature mineral phases.

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The principal families of the phaneritic (plutonic) and aphanitic (volcanic) rocks are shown in Table 1. This scheme expresses something of the *bulk chemical composition of the rock and the conditions of formation.* More specific rock types may be indicated by prefixing some pertinent mineral, textural, or structural term to the appropriate family name (such as biotite granite, graphic granite, orbicular granite). See PEGMATITE.

Chemical composition of igneous rocks. By averaging a large number of chemical rock analyses one may derive a representative composition for each of the rock families. Average analyses for the more common igneous rocks are shown in Table 2. Such average values are very useful standards for

Table 1. Classification of igneous rock families

	Feldspar	Quartz	Quartz or feldspathoid ( )	Nepheline	Leucite
Alkali feldspar and plagioclase (oligoclase and andesine)	Alkali feldspar [illegible] 50 [illegible] of the feldspar	Granite (P) Rhyolite (A)	Syenite (P) Trachyte (A)	Nepheline syenite (P) Phonolite (A)	Leucite phonolite (A)†
	Alkali feldspar [illegible] of the feldspar	Granodiorite (P) Quartz latite (A)	Monzonite (P) Latite (A)		
	Alkali feldspar [illegible] of the feldspar	Quartz diorite (P) (tonalite) Dacite (A)	Diorite (P) Andesite (A)		
Labradorite-anorthite			Anorthosite (P) Gabbro (P) Basalt (A) Diabase (H)	Theralite (P) Tephrite (A) Basanite (A)	Leucite tephrite (A)† Leucite basanite (A)†
Plagioclase < 10%			Peridotite (P) Pyroxenite (P) Hornblendite (P)	Nephelinite (A) Nepheline basalt (A)	Leucitite (A)† Leucite basalt (A)†

*See article [illegible]. † See LEUCITE ROCK.
(P) Phaneritic (plutonic) rock. (A) Aphanitic (volcanic) rock. (H) Hypabyssal rock.

mp ri ▪ pit of th fa t that the ar at ons w th n f m l es m y be gre ter th n those b twe n fam l es.

Mineral composition of igneous rocks Igneous ock f rm ng m al may be cla ed a pr mary se o d ry The pr m ry mm rals ar tl e formed by direct cry tall zation f m the magn a Se ondary minerals may form at a y sub quent t me

Ess ti l p imary minerals The principal pri mary mi erals a e rel tively few and may be l ss d as light col red (fel i) or d rk col red

T bl 2 Average chemical compositions of gneous rock (fter D ly) (t tals educed in 100%)

Compo ts	Pl to rocks							
	G ant	Grar o-d o te	Quartz d it	Sy te	M n o-n t	D o t	Gabbro	Nephelme syen te
SiO_2	0 18	6 01	61 59	60 19	56 1	6 7	49 4	54 63
TiO_2	39	57	66	67	1 10	84	9	86
Al_2O_3	14 47	15 94	16 1	16 8	16 96	16 67	17 88	19 89
Fe_2O_3	1 57	1 74	54	74	[illegible]	3 16	3 16	3 3
FeO	1 78	[illegible]	3 77	3 8	4 01	4 40	5 9	0
MnO	I	07	10	14	16	13	13	3
MgO	88	1 91	80	49	3 7	4 17	7 51	87
CaO	1 99	4 4	38	4.30	6 0	6 4	10 99	2 51
Na_2O	3 48	3 0	3 37	3 98	3 67	3 39	55	8 5
K_2O	4 11	7	10	4 49	3 76	1	[illegible]	46
H_2O	84	1 04	1	1 16	1 0	1 36	1 4	1 3
P_2O_5	19	0	6	8	47		8	

Compon ts	Aph t ocks							
	Rhy l te	Q tz lat te	Da te	Tra hyte	Latite	Andes t	B salt	Pl o olit
SiO_2	80	6 43	65 68	60 68	57 6	59 59	49 06	57 4
TiO_2	33	8	57	38	1 00	77	1 36	41
Al_2O_3	13 49	16 1	16	17 4	16 68	17 31	15 0	0 60
Fe_2O_3	1 4	4 04	38	64	9	3 33	5 38	3
FeO	88	1 0	1 90	6	4 0	3 13	6 37	1 03
MnO	08	09	06	06	10	18	31	13
MgO	38	1 4	1 41	1 1	3.2		6 17	30
CaO	1 0	4 4	3 46	3 09	4	5 80	8 9	1 0
Na_2O	3 38	3 34	3 97	4 43	3 59	3 59	3 11	8 84
K_2O	4 46	3	67	5 74	4 39	01	1 5	5 23
H_2O	1 47	1 90	1 0	1 6	91	1 6	1 6	04
P_2O_5	08	7	15	4	36	6	4	1

T bl 3 App oxim t mi ral composition of th common plut n c ock

Rock	F ls m rals	%	M fi min als	%
Gra t	P tass m f ld pa 35–4 Sod pl gioel se 0–30 Q rt 0 30	80–9	B otite h nbl nd	5 0
Gra od te	P tass m f ld par 15 –5 Sod pl gioclase 35–4 Q rt 1 –5	5–90	B t te hornbl nd	10–
Q rt d rite	Oligocl se ndes 55–6 Q tz 1 –5	0–8	H rnbl d b ot t pyro e	15 30
Syen t	P t m f ld pa 0 5 P t m f ld pa 60 0 Sod pl gioel se 10– 0 Qu t z 1 0–5	0–90	B ot te h rnbl d pyro e	10 30
M on te	P t ssi m f ld pa 0–30 Sod pl giocl se 4 5 Q tz or ph l 0–5	65 85	B t t hornbl nd pyro n	15 3
D rit	Ol gocl se des 60 0 P t ss m f ld pa 0– Q t ph l 0–5	60–80	H rnble d b ot t pyrox n	0–40
G bbro	Labrad rit b yt w t 0 P t m f ld pa 0 Q tz pl l ne 0	45–	Pyro ne l h rnbl d b ot t	5

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Table 1. Classification of igneous rock families

	Feldspar	Quartz	Quartz or feldspathoid (< 10%)	Nepheline	Leucite
Alkali feldspar and plagioclase (oligoclase and andesine)	Alkali feldspar > 2/3 of total feldspar	Granite (P)* Rhyolite (A)*	Syenite (P)* Trachyte (A)*	Nepheline syenite (P) Phonolite (A)*	Leucite phonolite (A)†
	Alkali feldspar 1/3–2/3 of total feldspar	Granodiorite (P)* Quartz latite (A)	Monzonite (P)* Latite (A)		
	Alkali feldspar < 1/3 of total feldspar	Quartz diorite (P) (tonalite) Dacite (A)*	Diorite (P)* Andesite (A)*		
Labradorite-anorthite			Anorthosite (P)* Gabbro (P)* Basalt (A)*	Theralite (P) Tephrite (A)	Leucite tephrite (A)†
			Diabase (H)*	Basanite (A)	Leucite basanite (A)†
Plagioclase < 10%			Peridotite (P)* Pyroxenite (P)* Hornblendite (P)*	Nephelinite (A) Nepheline basalt (A)	Leucitite (A)† Leucite basalt (A)†

*See article by this title. †See LEUCITE ROCK.
(P) Phaneritic (plutonic) rock (A) Aphanitic (volcanic) rock (H) Hypabyssal rock

c mp son in pite of the fact th t the ariatio s w th f m l es m y be great r than th b tween f m l es

Mineral composition of igneous rocks Igneous ock f rming mi rals may be I ed a pr m ry ec ndary Th p imary m neral are thos f rmed by di ect cry tallizat on f om the magma Se ndary m neral may form at any b equent t me

Esse n I p imary m erals The principal pri mary mi erals are relati ely few and may be las ed as light colored (felsic) or dark colored

Tabl 2. Averag hemical composit ons of igneou rocks (fte D ly) (totals ed ced to 100%)

Compon nts	Plut nic rocks							
	Cra it	Grar o- d te	Qu rtz d o t	Sy nite	Monzo- te	D o t	Gabbro	N pl line syen t
SiO_2	0 18	6 01	61 59	60 19	56 1	56 77	48 4	54 63
TiO_2	39	57	66	67	1 10	84	97	86
Al_2O_3	14 4	1 94	16 1	16 8	16 96	16 6	17 88	19 89
Fe_2O_3	1.57	1 74	1	4	93	3 16	3 16	3 3
FeO	1 78	6	3 77	3 8	4 01	4 40	5 9	0
MnO	1	07	10	14	16	13	13	3
MgO	88	1 91	80	49	3 7	4 17	7 51	87
CaO	1 99	4 4	5 38	4 30	6 50	6 4	10 99	.ol
Na_2O	3 48	3 70	3 37	3 98	3 67	3 39	.55	8 6
K_2O	4 11	75	10	4 49	3 6	1	89	5 46
H_2O	84	1 04	1	1 16	1 0	1 36	1 4	1 3
P_2O_5	19	0	6	28	47		8	5

Compo ts	Aphan t rocks							
	Rhy l te	Q a tz l t t	D c te	Tr hyt	Lat te	Andes te	Basalt	Phon l te
SiO_2	7 80	(43	65 68	60 68	57 65	59 59	49 06	57 45
TiO_2	33	8	7	38	1 00	7	1 36	41
Al_2O_3	13 49	16 15	16	17 4	16 68	17 31	15 0	0 60
Fe_2O_3	1 4	4 01	38	64	.29	3 33	5 38	3
FeO	88	1 0	1 90	6	4 0	3 13	6 37	1 03
MnO	08	09	06	06	10	18	31	13
MgO	38	1 74	1 41	1 1	3..	.7	6 17	30
CaO	1 0	1 4	3 46	3 09	5 4	80	8 9	1 50
Na_2O	3 38	3 34	3 97	4 43	3 59	3 8	3 11	8 84
K_2O	4 46	3 7	67	5 74	4 39	01	1	5 3
H_2O	1 47	1 90	1 50	1 6	91	1 6	1 6	.04
P_2O_5	08	7	15	4	36	6	4	1

T bl 3 Appro im te m eral composit on of the mmon pluton ocks

Rock	F l minerals %	%	M f c minerals	%
Gra t	P tass m f ld pa 35–45 Sod pl g oclase 0–30 Q a t 0–30	80–9	B t t h nbl nd	5– 0
Gra odiorit	P ta m f ld pa 15 – Sod pl g ocl se 35–4 Q t 1 –	0	B t t h rnblend	10–
Qua t d rit	Oligocl se des 55–6 Q t 15 –	0–85	H rnbl d b t t p y o e	15–30
Sy t	P ta m f ld pa 0–5 I ta m f ld pa 60– 0 Sod c pl gioclase 10 0 Qua t ph l a 0–5	0–90	B t te h rnbl d pyro ene	10–30
Mon t	I t s m feld pa 0–30 Sod pl gioel se 45–5 Q t nepl l 0–5	65–85	B t t H rnbl d pyro	15 3
D t	Ol goel se a des 0– 0 I t m f ld pa 0– O t ph l 0–	60–80	Hornbl d bi t t pyro n	0–40
G bbro	Labrad t t yt t 5 0 4 I t um f ld pa 0 5 O t o neph l ne 0		Pyro l h rnbl d b ot t	5

(mafic) varieties Fel ic is a mnemonic term for feldspathic minerals (feldspar and feldspathoids) and silica (quartz, tridymite and cristobalite) Mafic is mnemonic for magnesium and iron rich minerals (biotite amphibole pyroxene and oli vine) Fel ic minerals are compo ed largely of silica alumina and alkalie Mafics are rich in iron magnesium and calcium

Table 3 summarizes the essential primary con stituents of the more common plutonic rocks The percentage ranges are highly generalized Individ ual rock specimens may depart radically from these values but the averages are fairly representative and useful for comparison The mineral composi tion of the corresponding volcanic rocks is roughly similar to the values in the table Major departures will be encountered particularly in the glassy rocks

Accessory minerals Accessory minerals are those occurring in very small or trace amounts They con sist principally of magnetite ilmenite pyrite hem atite apatite zircon rutile and sphene Most gen erally the e are widely distributed as tiny grains or crystals

Secondary minerals Included in this group are minerals formed by addition of material subse quent to solidification of the rock or by alteration of minerals already pre ent in the rock The addi tion of fluorine and boron which tend to concen trate in the residual magmatic liquids to already crystallized portions of the rock may form small crystals of fluorite topaz or tourmaline Alteration in which certain minerals become more or less re constituted is common and widespread It is gen erally believed to occur during the la t stages of solidification while hot re idual fluids (for exam ple water and carbon dioxide) permeate the crystal aggregate and convert water free silicate minerals into l ydrous forms This hydrothermal or deuteric effect may be so inten e that virtually all igneous characteristics of the rock are lo t The common alteration product deri ed from the essential pri mary minerals are listed below

Primary mineral	*Secondary mineral*
Quartz	Not altered
I otash feldspar	Kaolinite sericite
Plamocl se	Kaolinite sericite (para onite) epidote zoisite calcite
Nepheline	Cancrinite analcite natrolite
Leuc te	Nepl eline and p tash feldspar
Sodalit	Analcite ancrinite
Biotite	Chlorite spl ene ep lote rutile iron oxi le
Hornl lende	Act nolite l i tite cl l rite epi dote calcite
Orthopyr xene	Anti orite actinolite talc
Clinopyroxene	Hornl lende actinolite b otit chlorite epid te antigorite
Olivine	S rpentine m netite talc mag nesite

Density of igneous rocks Den ity is a ignif cant rock pr perty and is a functi n largely of min eralogical composition and poro ity Chemical composition alone is not a relial le indication of density becau e different minerals (with different den ities) may form from a single bulk compo i tion

Table 4 Approximate densit es of some common plutonic rocks

Rock	Av g	C r ge
C anit	[illegible]	60 73
G a od it	[illegible]	6
Sy	6	6 8
Q tz l t	[illegible]	9
D o t	8	7 9
C l b o	99	8 3 1

Table 4 gives the approximate average and com mon range of density for the more abundant plu tonic rocks Densities of volcanic equivalents are generally slightly lower due to higher poro ity and greater amount of gla s Highly porous volcanic rocks (pumice and scoria) may be so vesicular as to float on water The density of compl etely gla y rocks is approximately 6% less than that of the corresponding holocrystalline (entirely cry tal line) type [C A CA]

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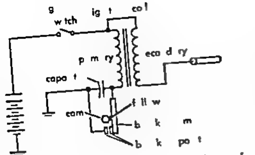
Ignition system

The ignition system of an internal coml u tion en gine initiates the chemical reaction l etween fuel and air in the cylinder charge F r maximum effi ciency it is neces ary to ignite the charge in each cylinder shortly before the pist n reaches the top of its compression stroke The be t timing i de termined experimentally f r various engine sp eed and loadings and the igniti n system i de igned t provide this timing automatically For smo th running multicylinder engines are usually l uilt n that the various piston arri e at their firing t p center positi ns in e enly spaced interval Tl e e quence in which the cylinders reach tl eir firing points depends up n tl e ge metrical arrangement of the cylinders and crank haft and is called the firing order of the engine The igniti n y tem di tril ute the igniti n impul e to the cylinders in thi rder (*s e* DISTRIBUTOR)

A large clas of engine including m t auto mol ile engine operate n a premixed harge f fuel apor and air In the engin the harge i ignited l y pa ing a l igh ltag l tri current l etween two electrode in the oml i ti n haml er (*see* SPARK PLUG) The ele tr le are in rj rated in a removal le unit When a spark f iff ient energy jump tl e gap l etwe n the ele tr d a elf pr p gating flame i pr duced in tl e fuel air mixture which pread raj i lly thr ugl o it th charg

Battery system Tl e el ctric energy f r the spark is oltai ed from a t rage l attery in pra tic lly all park igniti n engines Tl l tt y i n



g 1 B tt ry g t yst m (F m A R R g w k f f l t l-c mb st g M G w-H ll 953)

lly 6 r 12 lt i part f a l w lta e p mary i t whi h ncl d a switch the p im ry w d g f the ign ti n c l a p ctor (o c n d r) d b aker p nts (F g 1) Whe th w t h a d breake p t a e cl ed r t fl w f m the b tte y th gh the p im ry w d g th ugh the p t a d b k t th b ttery th o gh the ng e f me r oth r gr u d c n ect n Th l w nd abo t oft i on The urr nt in th p m ry w nd ng ndu e magn t fi ld n d r d th c Whe th br ak p t p a th e g ed n am t tes the u e t p h h h d b e p ng th gh the po nt w fi t t the apa t A th c p c to bec mes h rg d th p imary nt f ll r p dly a d th m g t field c ll p

Th ec d ry w d g t f ma y t rn f fi e w re w d n the ame w th th p imary d g The p d ll p of th m g et c field th n e i du es ry high lt ge i the ec d ry w d g

W th t th ap it the p im ry lt ge ed b th p d ll p e f the m g et fi ld d th p m y w d g w ld a e n re the b e k p t Th re w ld b rn th po m d soo d t y them Th e pac to l t th p d d p th p mary cu nt and ll p f th m gn t fi ld b th f wh h eces ry f r th p d t n f the high se d ry lt ge

Th ec d ltag led t th p k pl g p p q e by a tary w t h ll d th d i b t wh h d e by the m h ft th t d th b k po t m F m th he d f the d trib t w ll i lated w e ry th seco d ry lt ge t th t l lect od f the p ll pl g Th d h rge wh h t kes pl betwee th t l lect od d the g ded elect de d th mb t h mb ign t th cyl nde h g

Th t m g f th gn t n p k t lled by th pe g f th b k r po t Th g ti t m g m be ed by otat ng th pl t po h h th b k po t m ted el t t th m T m g m lso be ed by h g g th g l l t h p betwee th k am d th h ft that d es t

Magneto system The magneto sy tem s s milar to the batt ry sy tem e cept that the oltage re qu red to a e a ll w of current in the primary wi di g is generated by th tat on of a et of p rmanent magnet in t ad f bei g i ppl ed by a battery The mag et as mbly n rmally in l de w th n o e h u i g the rotating magnets ign t on coil windi gs i on core break r po nts am ap c t r and d t ibut r (Fig 2)

Rotati n f the m gnet a mbly completely re e ses the d rect o f the ma netic flu in th oft r n co e about wh ch the p imary and econdary o l a e w und Thi r p d change in fl x intensity a d d ecti n d s a c rrent thro gh the pr mary ci t. Whe the pr m ry urrent eaches a h gh l e a d th c tr but on to the t tal fl x is pri ipally f om th prim ry curre t a d n t fr m the e rm n nt magnets the bre k r p int open with the ame r s lt as in the battery sy t m d scr bed

For ma imum eco d ry voltag u s es e ti l that the b e ke po t open whe the p rma ent magnet ha e rea hed p rt cular pos ti n with respe t to the o l c re Any attempt to ary igni t o t m g by h fti g the pe ng t me of the b eaker points w ll th r fo e r s lt i a weake spark

Th magneto s ofte u ed n m ll ompa t in t ll t on h a l wn m we d utb a d e g es n wh h a battery w uld r pre ent e tra bulk a d we ght a d req ire replacement r re cha gi g t me In nstall tion h autom bil in which a battery is equ red fo i h other p r p ses a st t g pa k ng l ght d f el g ge o in wh h o de ble a ati n gnit n tim i g i ne es ry b ttery ign t n ystem s u u ally ch e

Compression ignition In th d l or omp s s n g it n e gi e the nd t d cyl de r is he ted uffi e tly by th mpre on tr ke of the p to th t ign t t kes place h rtly aft r the f l i p ayed i t the cyl der (see CO IBUSTION CHA IBER) Ign t t m g is th e t lled by the phasi g f th fuel i jection p mp wh le th

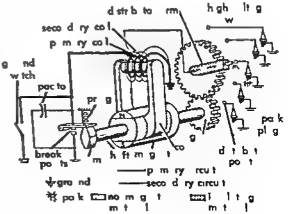


Fig 2 M g t ig t y t m (F m C H Ch t f ld C F T yl d S Ob Th A pl d It E g 5th d M G w-H ll 1949)

firing order of the cylinders is e tabli hed by the geometry of the pump In compre sion ignition en gine the fuel l urns as oon after ignition as it i able to find air with which to combine o that less attention need l e paid to automatic injection tim ing control When control i u ed pump haft po sition relati e to engine shaft can be changed au tomatically by centrifugal weights and a mechani cal linkage

Sometimes in small engines a premixed charge of fuel and air i ignited near the end of the com pression troke by the temperature of compre ion Under the e conditi n the entire charge once ig nited burns rapidly since all parts of the charge are equally heated and prepared for coml u tion The result is rough pounding coml ustion due to the high reaction rate No preci e way exists to control the exact timing of ignition with this method o that the coml u tion may occur too early or too late depending upon such factors as the temperature of the cylinder and the kind of fuel being used efficiency with uch ignition is likely to be poor [A R R]

Ignitron

A single anode mercury pool gas tube operating in the arc region An ignitor i employed to initiate the arc cathode pot before each conducting period *See* GAS TUBE

Ignitron principle The ignitor is a tationary electrode of emiconducting material uch a boron carbide which extend into the mercury pool A current pulse through the ignitor starts the arc at a de ired time in each cycle of the ac anode voltage by forming a cathode pot on the mercury surface Either a thyratron tul e or a emiconductor rectifier may be u ed to deliver the firing impul e to the ignitor *See* MERCURY VAPOR RECTIFIER

The tube is nonconducting regardle s of anode potential until a ource of electr n i upplied to initiate ele trical l reakdown of the ga within the tul e The cathode p t f rmed by the ignitor up plies the needed electrons to create an electron a alanche which terminate as an arc Once the arc ha been f rmed the atl de pot i maintained l y the arc current and the action of the ignit r is terminated

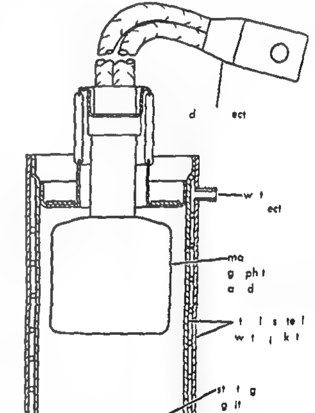
The ignitron remain c nducting until the an de potential i rem ved and f r me micr econds thereafter until all tl e ions ha e l ecome deioniz d

The repetitive tarting techniq ie employed with ignitron makes p il le a hort an de to cathode pacing re ulting in l w voltage dr p and l igh efficiency In addition ingle anode tube like the ignitr n and the excitron are uniq e am ng ga filled tul es in their al ility to carry high overload and hort circuit current withou t ap r tarvati n urge Thi re ult fr m the u e of the exc vapor pre ure generated l y the erl ad Th normal vapor pres ure i c ntrolled u ally l y water cooling at a alue sufficient for l e t opera tion at rated l ad The coml ination of a mercury pool cathode and a short anode-to-cathode pacing make it po ible for the exce s vapor generated by the overload current to fill the di charge pace ju t when needed and then conden e on the walls in time for the next cycle of normal operati n

Ignitron types There are tw o cla e of ignitrons e pecially de igned for different kind of ervice The e are the welder and the rectifier ignitron

Welder ignitrons Thi tube is u ed in pair con nected inver e parallel to operate a ac contactor and control the primary current upplied t re sistance welding tran formers

Welding ignitron are of relatively open con struction with little hielding and are de igned specifically to carry the high current encountered in resi tance welding In welding ervice the anode current wave is sinu oidal and the current de crea es to zero o lo ly that the re idual vapor bla t and ionization pre ent at the l eginning of the inver e period i low enough that it doe not cau e arc back Furthermore only the tube that conducts la t is ubjected to inver e voltage im



F g 1 S aled Ig tr fo w ld s rvice (G al El t c)

med at ly f ll ng c ndu t on The condit n perm t the u e of tubes w th ut spl sh baffle d s n zi g baffle and gr d Th e n tr cti n of typ l e led ign t on for w ld ng ervice is shown i Fig 1

R ct fi r gnitr ns Th s gnitr n s g ner lly ed t f x t co rt p we from ac t dc Th m ller t be a e of s al d c n tr cti n The la ger un t a b ilt n ta ks which ar eith r a uum al d or co t nuou ly acuum pumped

R tifi r g tr ns ar eq ipped w th b ffl th pa between th anode a d c thod to pr e t the apo lla t f om thr w ng merc ry d ops ag n t the f f the an de a d t help dei n ze th me ury ap r In the la g r e the an d to nded by one or mo e gr ds t mc a se the rate f de nizat n f the ap c adjac nt t the anode d t pr id add t al co t ol of th tart f a ode co d ction The n t cti n f a typ c l h gh-c rr t g tr n f r ctifie e hown i F g

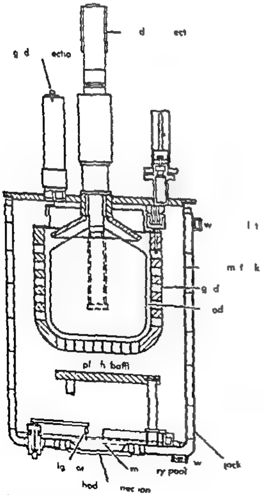
Firing circuits Ign t r req re a pul e f cur nt of 5-50 amp es n th f rwa d d re ti n from the ignitor to the mercury to tart c thode pot Since th gnitor esi t nce v rie from a few to seve al hu dred ohms po ti voltage of everal h i dred olts mu t be mpr ssed n t

The olt ge and current applied to the i nitor n th re r dir t n must be limited to low v lue to a id damage Speci l circu ts have been de i ed to deliver the fri g p l e t the ign tor and pro id cont l of the t me of firing

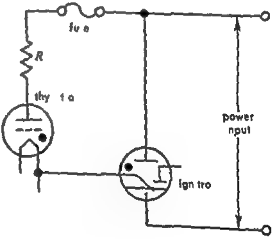
Anode firing ci cuit Th power cir uit v ltage which app ars betw en an de and cathode just l e f r cond cti n s u ed t fi e the igr itor in the rcu t hown in Fi 3 Thi c rcu t is w dely u ed i ign t o conta t r (re ta ce weld ng) ers ce

Cap cito fir ng circu t A apacitor that ha b e charg d f m n au ili ry ac power rce is d sch ged thr u h th ign tor at the d sired moment in the c cl by a thyratron t be n the ci cu t h wn in F g 4

Mag etic fi i g cir t Many ignitro rect fi a quipped w th m gnet c fri g to obtain l g r l fe and g eate r li bil ty than is po sible with thy t on fir g tube I the c rcuit th capa



F g 2 S gl g id p mple ect fi ig it (G n ral El)



F g 3 Elem tary n d f g c t

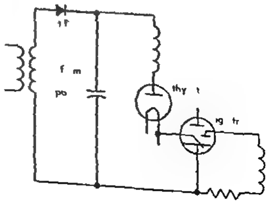


Fig 4 El m t ry t f c p t fi n t ig t

tor is discharged through the ignitor by saturating a reactor which is connected in series with the capacitor.

Ignitron tubes and tanks are built in size ranging from [illegible] to 20 in. in diameter. Ratings range from 25 to 1000 amperes average per tube at voltages from 250 to 20,000 volts and higher.

[C.C.H.]

Bibliography: W. G. Dow, *Fundamentals of Engineering Electronics*, 1952; J. Slepian and L. R. Ludwig, A new method of initiating the cathode of an arc, *Trans. AIEE*, 52(2):693–698, 1933.

Ileitis

Regional ileitis is a sharply demarcated inflammation of the lower portion of the small intestine. Actually, other portions of the small and large intestine may be involved, so regional enteritis or regional enterocolitis may be preferred terms.

The disease is marked by intestinal obstruction, pain, cramps, diarrhea, and constipation. There is often associated weight loss or anemia. Late in the disease, after a long but often vague history, the bowel appears thickened and firm and has a nodular mucosal lining which shows variable ulceration and inflammation. Adjacent segments may show little or no change.

The cause is unknown, but faulty protein absorption, psychic factors, and abnormality of lymphatic drainage have been implicated by various investigators. Although regional ileitis is found most often in young adults, no age group is immune.

The clinical course is typically erratic but progressive in most individuals. Neither medical or surgical treatment offers a guaranteed cure because extension to previously unaffected bowel segments may occur.

In contrast to regional ileitis, ordinary ileitis is any inflammation of the ileum from specific causes such as trauma or infections such as tuberculosis, typhoid fever, and dysentery. *See* INTESTINE; INTESTINE, DISORDERS OF. [E.C.S.T.]

Illite

The term illite is not a specific clay mineral name but is a general term for the mica-type clay minerals. It is commonly used for any nonexpanding clay mineral with a 10-angstrom *c*-axis spacing. *See* CLAY MINERALS.

Illite clays are used for the manufacture of structural clay products such as brick and tile. Some degraded high-plastic illites are used for bonding molding sand. *See* CLAY, COMMERCIAL; CLAY PRODUCT, ARCHITECTURAL.

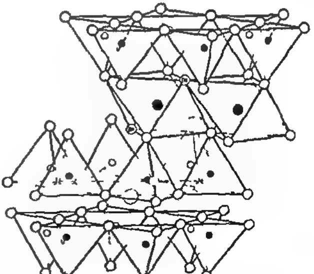
Structural characteristics. By definition all illites have the mica-type structure. The basic structural unit is composed of two silica tetrahedral sheets with a central octahedral sheet. This unit is essentially the same as that of montmorillonite except that there is always some replacement (15% ±) of silicon by aluminum in the tetrahedral sheets. This substitution results in a charge deficiency which is balanced by potassium ions between the illite unit layers. The stacking of adjacent illite layers is such that the potassium just fits and is always surrounded by a total of 12 oxygens, thus balancing the structural charge and binding the layers together without the possibility of expansion (see Fig. 1). Illites may be either dioctahedral or trioctahedral, depending on the population of possible octahedral positions. They differ from well-crystallized micas in that they exhibit less substitution of aluminum for silicon, resulting in a higher silicon to aluminum molecular ratio.

Nonstructural characteristics. The size of naturally occurring illite particles is very small, yet they are larger and thicker than montmorillonite particles and have better defined edges.

The illites have a moderately low cation exchange capacity (20–30 milliequivalents per 100 grams). It is primarily due to broken bonds, but lattice substitutions may also be a cause in poorly crystallized varieties. The rate of the exchange reaction is likely to be slow, since a small part of the exchange occurs through partial replacement of the firmly held interlayer potassium ions.

Dehydration curves for illites show the presence of a small amount of interlayer water which is lost below 100°C. The OH lattice water is lost between 300 and 600°C. Following the loss of structure between 850 and 950°C, spinel and mullite phases form prior to fusion at about 1400°C.

Occurrence. Illite is a common product of weathering if potash is present in the environment of alteration. It is a frequent constituent in many soil types and may form in soils under certain conditions as a consequence of the addition of potash fertilizers. This is possible because illite has the ability to fix potassium. Much illite in soils loses its potassium through leaching and becomes degraded. On the addition of potassium to such ma-



O oxygens O hydroxyls ● aluminum ◯ potassium ⊙ and ● silicon (one fourth replaced by aluminum)

Diagrammatic sketch of the structure of illite. (From R. E. Grim, *Clay Mineralogy*, McGraw-Hill, 1953)

t r l k goe back t t these normal po t on a d the ill te eb ilt *See* SOIL.

Ill te t common r rec I sed ments and is par t larly ab nd nt n d ep- a clay It probably forms f m mo tm rillonite and other m eral d i g marine d ge es B cause f t stab l ty ll te fte fo nd in anc ent ed m nt It is the d m nant clay mine al n many probably m t h les that ha been tud ed *S* DIAGE ESIS MARI E EDIME TS SHALE [F M W R E C R]

Illuminance

A te m e p e ing th lum n s flux fall ng on a rfac Th word h s been prop ed by th Col imetry Comm tt e f th Opt al Soc tv f Am to epl ce th term Il im nati n Th def iti n ar the same

Th ymbol of ill m nati n i E and the qua t i $E = dF/dA$ wh r A is the a e f the ll minated u f ce and F the lumin us flux *S* ILLUMINATIO PHOTO IETRY [R C P]

Illumination

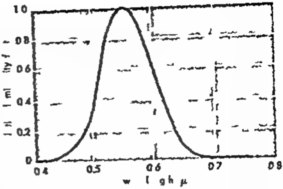
I a g e al en e the se n e of th appl ati n of l ght ng Rad t on in th ange of w velength f 0.38–0 6 m n (μ) produ es the i ual ffect mm ly lled l ght by the resp nse of th a er age hum ye f r normal br ll n levels Illum ati n eng e ng pert s t the ur e f light ing a d th d gn f l ght g y tems which d trib t l ght t ffect a omfort bl nd ffec t e i nm t fo e g

In pe fic q a t t tr e llum n t on (met mes alled llumin nee) the c mb nat on f th pati l d n ty f rad ant p we ec ed at rf and th ffect e ess of th t radi t o in p odu i g a u l eff t *S* ILLUMINANCE

Luminosity curve of human eye A standa d espo e f th h m ye to rad ti n at normal l ill n le el wa tabl h d by i t rn t o al g eem t 1924 by La Comm n Inte nat o- al d l É la g th o gh the f nct n kn wn a th CIF al es of bil ty (Th lett s ICI f th E gl h m a lso ed) Th d nate f th f n r ch pl tted ag st th w l ngth f r d ti F g 1 nd are t b lat d in th t l I Th d n t mm ly alled th

Rel tive l mi osity factor (val ity 0 554 wavelength)

W e- le g h,	F ctor	W e- l th,	F	W e- l gth,	F to
0 38	0 00001	0 51	0 503	0 64	0 1
0 5	0 0001	0	0 10	0 6	0 10
40	0 0004	0 53	0 86	0 66	0 061
0 41	0 001	0 54	0 9 1	0 6	0 03
0 4	0040	0 5	0 99	0 68	0 017
43	0 011	0 56	0 99	0 69	0 008
44	0 3	0	0 9	0 0	0 0041
4	0 038	0 8	0 8 0	0 1	0 00 1
4	0 060	0 9	0	0	0 0010
0 4	0 091	0 60	0 631	0 3	0 000
48	13	0 61	0 503	0 4	0 000
4	0 08	0	0 381	0	0 0001
50	3 3	0 63	0 6	0 6	0 00006



Fg 1 Lum ty curv f th h mo y (F m *W B 8 o t Ill m n t E g* g 2d d M G w H ll 1953)

rel t v l minos ty factors *See* LUMINOSITY FAC TOR

At th esh ld level of e i g th spectr l re- p e function f the eye i hifted toward l wer wavel ngth This effect is known a th Purki je effect

Photometric definition Illuminati n (or illu min nc) i the d ns ty of radiant p we incide t up n a ece ng s rfa e ev lu t d through ut the pe trum in term f th ICI val es of i ib lity F r a l e-spe trum compon nt of irradi ti n a impl multiplicati n of the irr d ation compo- n nt G and the valu f relati e luminosity factor v taken t the pr per alue f wavel ngth i yield the omp nent illuminat on F r co tinu us- t um i radiat o G i function of wavele gth the ef re th p odu t of the two functi ns v and G mu t be int grated St t d mathematic lly for a c mb n tion of l ne spe t a and continuo s pec trum ource

$$E = k \sum_i v_i G_i + k \int_0^\infty v_\lambda G_\lambda \, d\lambda$$

whe e G i the rrad t n due to th ith ompo n nt f the l ne p ct a s the elat e l mi os- ity fa t r t wa el ngth c rre pond ng to th w elength f the th omp n nt rr diation n i the numb of mponent l ne pe t a r diat on G i the spectral irrad ati n f the ont n spect m t λ wavelength v is the rel ti e lumi o ty f t t the rre p nd ng wa elength nd k i a co tant equal to 680 l mens/watt

Th tandard upon which all q ant tativ n ts n th field of Ilum n t on are based the bright n r lum na of a black body rad ato at the freezing poi t of pl t num (2042 K) The bright n h s b n ta da d zed by i t rnat onal agree me t t 60 c ndle / m² (or 60π l mberts) This alu t g th r w th Pl ck equ t n fo the r d t n d ty when evalu ted in te m of the lum nos ty fun t on y elds th co stant k of 680 lume s/watt *Se* LAMBERT LUMINANCE

Th lum n i the un t f lum n u fl th t re lt wh n r d nt pow r i evaluated th o gh th

luminosity function Any one of several units of area may be used to express the density of this luminous flux or the illumination In the English system the unit of illumination is the lumen/ft The term foot candle was coined in earlier evaluation techniques and probably will continue to persist in the terminology The lumen/ft and the foot candle are identical units *See* FOOT CANDLE ILLUMINANCE LUMEN LUMINOUS FLUX LUX PHOT

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Oil flame and gas lighting were used before the advent of the electric light but since about 1900 electric energy has been the source of essentially all modern lighting devices

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Reflection and transmission The control of light is of primary importance in illumination engineering because light sources rarely have inherent characteristics of distribution brightness or color desirable for direct application Modification of light may be provided in a number of ways all of which may be grouped under the general topics of reflection and transmission Reflection from a surface and transmission through it each may be classified according to their spatial and spectral characteristic

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Figure 2 illustrate the extremes of specular reflection such as would be obtained from polished metal or silvered glass and an ideal mat finished surface possessing microscopic roughness of minute crystals or pigment particle The specular reflector give a direct image of the source with the angle of reflection equal to the angle of incidence The plot shown for the diffuse reflector is the small area intensity distribution curve it exhibits a cosine distribution in the idealized case

Practical surfaces possess spatial reflection characteristics intermediate between these ideal particularly at the diffuse end of the range Typical distribution curves are shown in Fig 3 In all of these illustration the light source is small Figure 3a demonstrate that even with the best practical mat surface such as dull finished metal or those painted with flat paint the location of the source of light has some light influence upon the intensity distribution as evidenced by an irregularity of the cosine distribution of intensity of the small area of the surface Figure 3b and c demonstrate the pronounced influence of the location of the light source upon the intensity distribution for surfaces covered with semimat material such a

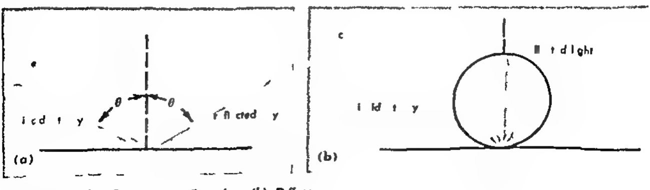

Fig 2 Ideal reflection (a) Specular (b) Diffuse (From W B Boast Illumination Engineering 2d ed McGraw-Hill 1953)

t n fin h p i r F gure 3d llu t at a m x d r flecti j h n m n n ≡ lt n wh n a diffu ing u f ≡ r o erla d th a urface p ing been

Spat l char te t f t an m i n r llus-t ted F 4 F g r 4a hows regula trans-p r nt tra m on i h a n urs w th l ar gla r pla t F g r 4b h ws the diffu tr ns-m tf at w uld r ult with a d al z d d ffu ing mate ial I F 4a a refr t of the trans-par t imag curs b t th angles θ and θ ar

T a t al t n mi on mater al y o e patial tr n m h t r t i t rmedi t betwe n th e d al d h b t nten ty d tributi n re ll t ated by F S Figu e 5 d mon tr tes that a p f ct nten its d t but o t t lt an d ev w th l d pal m lk gl s m t i L A m r d e t tr n m n i h wn in Fig 5b f a fla l ed pal gl m di m n wl h the m j r t of the ba m i l i cle r gla s S nd b l t d f ted gl mate l s mu h l d ff i d the lo ti n f th light u ce g tl i fluenc s th nte t d tr b ti n curve (Fig 5 d d

Sp r l A t t If a h m eneo ad ti n (w l gth λ mp nge up n u fa e th flect ha a t i t c o th t an m n ha t t ll res lt geom tr r ll a e d ng t th p t l n i d r t f the p d g t n The m gnit de l t t) power d n ty r fl ted or tr mitt d to th t d defi d a the p c t l fl t n f i ρ or the p t al tr m s on factor re pectively Thus $\rho = J/G$ and $= J/G$ whe e J is the reflected pectr l mis-ion at wavelength λ J is the tran m tted spec tr l emi i n at wa ele gth λ a d G s the spe tral i radi t on at wa length λ

A d ce f r mea ur n ρ or s called a spec tr ph tom t r Compar n of J r J with G (r its tial equ vale c) may l e ac ompl hed by i ual ph t electr c meth d of photometry See PHOTOMETE

E ther ntinu s- r l ne-sp ctra s urces of ir r d ati n m y con t t te a practical s urce of rad a t p w r dens ty The resulting s c nd ry source of adia t power density J or J will be modified c mp red w th the o g nal depend ng upon th spectral fl ction r t a m on character tic f the reflecti g or t ansmitt ng mate ial

An e alu tion f J r J ing the elative lumi n s t fa t r s may be effe ted for the econdar ource f radi nt p wer den ty in the am m n ner as i done f r cid nt adiant power den ity nd t s B th l ne nd c ntin ous spe t um ef fe ts m y be in luded as dem nstrated f r the eval t n f th illumination Th e aluation of the r fle t d tran mitted lum nou fl d n ity y i lds the lum ance ymb l d by L f r the re fle t n f and L for the transm tt u fa Th fun tio al operati n are h w g aphi c lly th r of curve of F g (for the r fl ti re ult ng f om a c nt nu s- pect um u e The rati f L r L t th llum nat n E e lt n $\rho = L/E$ and $\tau = L/E$ whe e ρ s the

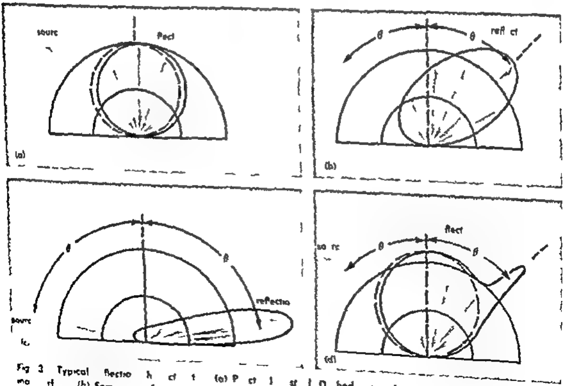

Fig 3 Typical flectio h ct t (a) P ct l st l D hed tv i ( ) d (d) ll t te d l o-mo rf (b) Sem m t rf ( ) S m m t rf d but (F om W B B t Ill m t E g long ngl f i sd (d) l n-e m l d g 2d ed McG w H ll 1953)

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Figure 2 illustrates the extremes of specular reflection, such as would be obtained from polished metal or silvered glass, and an ideal mat finished surface possessing microscopic roughness of minute crystals or pigment particles. The specular reflector gives a direct image of the source with the angle of reflection equal to the angle of incidence. The plot shown for the diffuse reflector is the small area intensity distribution curve; it exhibits a cosine distribution in the idealized case.

Practical surfaces possess spatial reflection characteristics intermediate between these ideals, particularly at the diffuse end of the range. Typical distribution curves are shown in Fig. 3. In all of these illustrations the light source is small. Figure 3a demonstrates that even with the best practical mat surface, such as dull finished metal or those painted with flat paint, the location of the source of light has some influence upon the intensity distribution, as evidenced by an irregularity of the cosine distribution of intensity of the small area of the surface. Figure 3b and c demonstrate the pronounced influence of the location of the light source upon the intensity distribution for surfaces covered with semimat material, such as

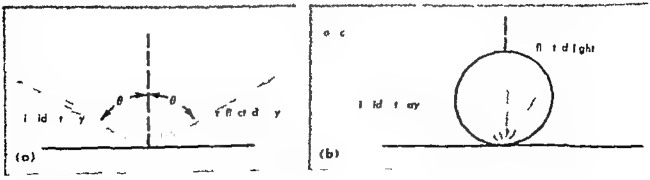


Fig. 2. Ideal reflection. (a) Specular. (b) Diffuse. (From W. B. Boast, Illumination Engineering, 2d ed., McGraw-Hill, 1953)

refl cti n fa tor of the urfac and i the transm on f ct r of the mat l The reflect n and t a m on fa t are dep dent up the ource of illumin ti n a well as th spect al cha cter ti s f the rfac or the tr n mitting med um Su h fact r a e frequently publ hed f r tungsten filame t l ght and ar u eful as gu des and i d ca t f magnitude if th our es f illum nati n d n t d iate too greatly f om th s pe tral di trib ti n

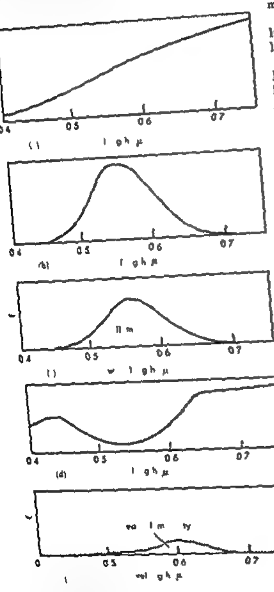


Fig 6 Th proc of vol t g l m f flect g surf f eval t ng th ll m t ( ) Spectral irradia io G curv (b) R l tive luminosity f ctor rve ( ) C rve f C Ill m t h he ea und this curve th i t grat f G d) Spectral reflectio f ct p rve ( ) C rv F p (mina is th ea d th curv the integ ion p IE m W B B st Ill m io Engineering 2d d McG aw-H ll 1953)

Light control methods Th character of th eflecting urf ce or transm tting material dete mine the deg e of l ght c ntrol pos ble If a li ht ray is r flected r tran mitte l diffu ely the hape of the refl cting r tran mitting urface i ul l ttle importan e alth ugh its ze may be of g eat importance A lar er diff urface will redu e the br ghtne s of the primary s rce If a light ray s r flected fr m a pecular urf ce more accurate cont ol f th l ght can be effect d

Pa ab l c efl ctors Th e r probably the mo t u eful of all r fl ct r f rms The rays eme e s ent ally p rallel f om such a reflecto if the li ht u ce is pla ed at ts focal point Se r h light u e p rabolic mirr r refl ctors

Ell pti eflecto s A relati ely large amount of light may be made t pa s thr ugh a mall opening bef pre d n out b u ng an ell pti reflector A li ht o e i placed at ne of the focal p ints f a nearly ompl te ll pt cal reflector A mall openi g is placed t the nd focal po nt where the light i focu d Such a de ign u ed for the p n h le spotl ht F r further d cu i n of r fl ctor *see* PROJECTOR (LIGHT)

L ns c trol Refraction of l ght rays at the boundary between gla s and air may be u ed to cont ol tr n m tted light in a manner similar to refl ct r o t l S mpl thick lense may be cut w y if the ut away p ece is duplicated n the new equ valent s rface Sli ht ir e ula it es in th fi ld of the l ght be m o ur Th e may be of l ttle n eq enc fo ar hli hts or fl odl ght but they would be undes rable for h gh qu lity p ture p oje tion *S e* LE s OPTICAL

Pola izat on of light Light ays mitt d by common sou ces may b c n de ed s wa e i li ti g at ll ngl plan s at ri ht angles to th d ect n of the ay As they pa thro gh me ubstanc s o a r flect d f m p c la urfa es, part cularly t c tain a gl s wa e c mp ents i m d e ti n a absorbed m r than th e i othe d e t n S h light sa d to be p la iz d Pol i ed light m y be cont ll d by a tr mit t g s ti n f polari g mater al Wh n the ab rbing s tio or ted t p rm t pas age of the p la zed l ght m nim m c nt ol is xerc ed If the ab o l i g se t n is t t d 90 th polar d l ght i s enti lly completely ab orbed Be c u l ght r flect d fr m w t r or p cular r f s s h ghly pola z d glar f m u h so rces eff t ely trolled by pol r z d sungl s r am a filte P la iz d l ght i u ed al o fo de te ti n of tr s a d d f cts in gla r plastics Th train d are s app s c lo fr th m t r l *S e* POLARIZ D LIGHT

Interior lighting design Att nm t of a com f table i l o ment i the lt m t go l o i t r i l ght ng de ign Th s eq e a dequat di tr bution of illum at o d cont ol of brigh es f ll i bl u fa t a o d xce i e con tra t Th ad q ate d t b t n of illum ti requi that fficient n mb f l ghti

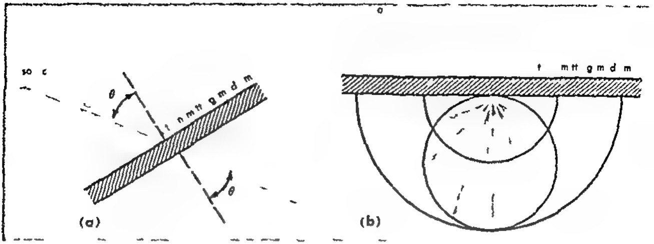
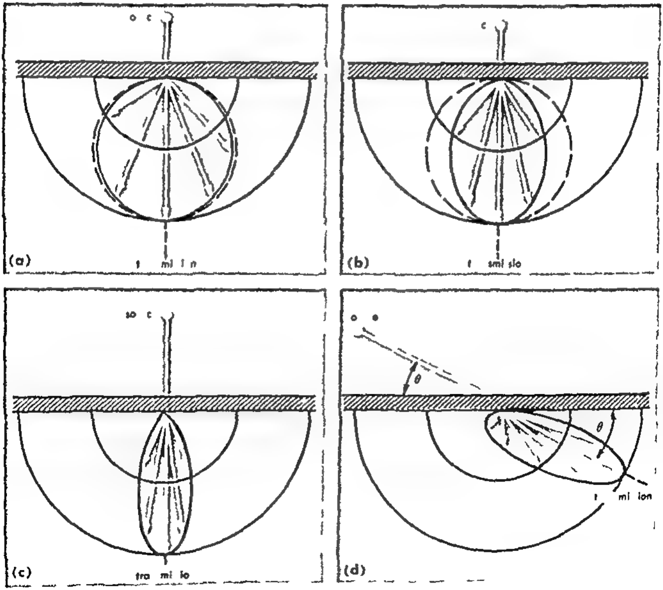


Fig 4 Ideal tra sm ss on cha acterist cs (a) Specular (b) D ffuse (F om W B Boast Ill m at o Eng neer g 2d ed McGraw H ll 1953)



F g 5 Typ c l t a m ss on cha acte t cs (a) Sol d opal glass (b) Flashed op l glass ( ) Sa d blasted glass (d) Sand blasted glass with cide t l ght at 30 f om pla e at rface (F m W B Boa t Ill m at o E g ee g 2d d McG aw H ll 1953)

er l l ght ng wh h gh les l of illumi att n is d rabl o an solated ta k Local l ghting that does t uppl m nt ge ral l ght g u ually doe t perm t conform nc w th the l m tati ns n b ghtnes c tra ts for nt rior light ng de gns

Exterior lighting design The htt me l ght g of t ri r at a rves many u eful purpo es Su h l ght ng e te d int the fi lds f ad ert ing and rec e t l p r u ts as well a t l t r an fi ld i h th l ght ng f nd m l yards pa k ng areas a rpo t treet a d h ghw ys The *IES Light g Handb ok* a d m ny t xtbooks t eat in d m l ma y f the e pec al zed appl at ons.

Automobile headlamps H adlamp n tw beam of d ffer nt ch ra t r t under the on trol f th d The a m g nd i t n ty f n beam d gned t prov d di tant ill mi at n Th tl r b am i med l w enough and in ch di ect o t p ev t glar f r coming dri er

Sealed be m h dl ght ha e been d n e b t 1940 Wh n filam nt b rns t *the enti e* l mp i epl d th a re t ring th parabol c re-flect s d nd t of alignm t of the l gl t sou e bett tha was p ble f r a epa ate lamp r p rman t flecto

Recommended standards of illumination Illu m n t les l ha e b e t l h hed by the Illu m n t ng Fng eri g Soc ty t b g all al ta k t th am lev l f ib lity f n m l ol rs Som l t k m e a d than th r and h gh r ll m t o p o de a *on* pe t ng f t r n b ng ng h ta k t a s t f t y lev l f b l t St dard est b l h d t ly f r nte i r l ghting d gns but lso f r t r o s t m l d g rec m t onal l gl t g F r t l l l mmended illum t n les l lt efer lt ted in th b bl gr phy

Colored light Th great t p ect n i col r pec fi at obt ned by th m f th p t al rves f t t a el gth f th d at o H wev f r t al n d t o it h s b f d that y l r m d f ompl p tral mpo nt m be m t hed ally b p p r t g th p pe ly h mpon t r dia l Th l t m gn tu d f thes th e m r t d t r lled th trich omat oeff i m l th l r Oth d gn t f d m t w l ngth d *pe tr l p* ty m y be f t ed lso f m thes tr h mat oeffi e ts s (t

[W A R]

B b g ph C. L. Am k *Fl s nt L ght g* M l d ed 191 W F B w *l ght* *Ih m* *d Ill m t g E g rt g* 3d ed 19 1 W H B ss t *Ill m t n E gin g d* ed 19 1 Ill m t ng F gi ee g Soc ty *IES L ght g H db ok* 3d ed 19 9 A F Kn ll n d *d H dbook f El t l E gi* 9th ed 1 J O K h nl hl *El t i Ill m nat* l ed 19 1 l H Moon a d D F Sp r *L gh g D g* 1948 H P d a J W A D l *M ed t El t l F g H dbook* s l l th ed 1949 H M sh p *I t od t t Light g* 19 1

Ilmenite

A m neral having compo iti n $FeTiO$ and cry tal l zing in the h x gonal y tem Ilmenite i found n cry tal that are tab la parallel to the b a al plane with rh mb hed al t ucat on but u ually m s-e Th hardn s is 5.5-6 (M hs cal) and the pe ific gra ty s 4.7 Th lu ter i m talli and the c l r i r n black Ilmenit s an acc ry m neral n igneou ks and n ome ba ic rocks i f und n la ge m s es res ltin from magmatic segr a t n i wh h it may l e i t mately a c ated with magnet te It i found in cry tals n the Ilmen Mountains, Rus a and n la g *q antiti s at* K age Norway a d Bay St Paul and Allard Lak Quebec In the Un ted States it i a ciated with the magnet te depo it f tl e *Adiro dack r* g on a d i mined as an re f titanium at Tahawa New Y k *See* TITANIUM [C.S HU]

Image acoustical

If point sou e of d is placed on on id f n xte d d effect ng urface it may be co id red t ha e an imag at an eq i alent d tanc on tl th r ide of the s cf ce al ng a perpend cular p oje t on nalog u t th f r lia opt al ma e (s e I IAGE OPTICAL) The ff ts of r fle ting urfa es on a *ou ti w ie* freq ently ca be p e *d ted by the* u f u l im ges A sou ce i f ont of a ery r fl ti wall (f r example plast r co c t and ma ry reflect 97 99% of i c d nt nd energy) will h e an image of trength alm t eq al t that of th ou ce ib at g in *pha e th the* ur T obta the t tal effect at any t *du to the* mbi ed act on of a urc a d su h r fl ti g u fac the effects du t th u c it lf d noth r ou e of equal t ength placed at the mag po nt a e dded If there i a ec d flect ng u f pres t th o-c ll d fi t-o de *m g* w ll h c n ima e called the co d-order im of the rce at an quiv le t di t nc n th th id f th nd r flecting i f S m larly image f the ond-ord mage id t b th d rder mag nd o on Alth gh th method is p ecι e nly when th fle ti g s rfa e i o ab orpt t i ften of n d rabl h lp n in est gati n of th act on of sound wa es n ooms *S* ARCHITECTURAL OUS-TICS [C M H]

Image optical

A pt cal im ge i tl e m f rmed b the l ght rays f m elf l min s o a llum nated object th t t rce an pt cal y t m Th m ge s sa *d* t be r al *if the l ght* ay con erg to a focus on th im g de and rtual if the *ra*y seem to m f m a po t with n the in trument (s e ill tr t n)

Th pti l m g of bject i g n by th l ght d trib t n th m g plan mi g fr m a h p nt f the object t th mage pl e f a pt l ystem The id al m l a p t c d ng t geom t al pt s obta ned when all rays

sources be installed in a manner that produces an adequate level and a proper distribution of illumination. Brightness is controlled by adequate surface reflection or transmission areas associated with the lighting sources and with proper reflecting surfaces within the room itself. Control should ensure that the brightest surfaces of the room are not more than three times the brightness of the work and the brightness of the work not more than three times that of the darkest surfaces in the room. When such brightness ratio limitations are satisfied, glare will be absent and a satisfactory visual environment is achieved. A proper application of color in the interior enhances the over-all appearance.

The function of a building greatly influences the manner in which lighting is applied. A particular visual task may require a certain level of illumination, but the lighting design is also influenced by the economics, appearance, and quality of desired result. For example, application techniques are designated as industrial lighting, commercial lighting, and school lighting. Certain application experience and consumer acceptance assume importance in the methods of achieving the level of illumination and control of brightness contrasts. The *IES Lighting Handbook* treats in detail many of the specialized concepts.

Location and spacing of luminaires. Many interior lighting designs utilize general lighting to distribute luminous flux throughout the room on an imaginary working plane, which is usually 30 in. above the floor. To accomplish a reasonably uniform illumination on this plane, certain limitations in spacing between luminaires and spacing between luminaires and walls must not be exceeded. The height of luminaires above the plane may be an important factor for some interiors. For indirect-type luminaires the distance from the ceiling to the luminaire must provide a proper distribution of light over the ceiling. See LUMINAIRE.

Room coefficients. The shape of a room influences the fraction of the emitted luminous flux that will be received on the working plane. Equations and empirical tabulations have been developed to classify rooms according to their shape. Large broad rooms are more efficient than small or narrow rooms for transferring luminous flux from the luminaire to the working plane, particularly if the reflection factor of the side walls is low.

Lumen method of illumination design. This empirical method of design gives the average illumination on the working plane for a particular number of luminaires arranged in a symmetric pattern in a room. The illumination that may be expected to be maintained in the room is

$$F = \frac{N\phi_L K M}{A}$$

where F is illumination in foot-candles (or lumens/ft²), N is number of luminaires, ϕ_L is initial lumen flux per luminaire in lumens, K is coefficient of utilization, M is maintenance factor, and A is area of room in square feet.

Tables of the coefficient of utilization are obtained empirically. Usually these tables pertain to a particular luminaire. The coefficient of utilization is a function of the room coefficient and the reflection factor of principally the ceiling and side walls. Also called the flux of light method, this was originally designed as a component method whereby the candle-power distribution curve of any luminaire could be resolved into three component curves and each calculated according to an equation similar to that shown. However, modern use of the method is principally through coefficients of utilization for each particular luminaire.

The maintenance factor M is a number less than one to account for lamp darkening and the collection of dirt within the luminaire, which reduce the illumination emitted from the luminaire.

Interreflection method. The interreflection of luminous flux within a room is accounted for in the empirical data of the lumen method. An exact mathematical calculation of the distribution of luminous flux within rectangular rooms becomes extremely involved. Various simplifying assumptions, however, permit an approximate solution for both the illumination upon the working plane and the brightness of various surfaces within the room. Tabulations of calculated data for the normalized illumination and brightness for interiors of various room coefficients and surface reflection factors are published in some of the references given at the end of this article. Conformance with the 3:1 or 1:3 brightness ratio criterion for a comfortable visual environment becomes a standard checking procedure in the application of the interreflection method.

Luminous architectural elements. The original emphasis in the lumen method was upon discrete luminaires arranged symmetrically within the room. The development of the interreflection method of design presumed surfaces of initial brightness on ceiling, wall, and floor as the sources of light within the room. Ingenuity in the application of both methods permits them to be applied both to designs involving luminaires within the room and to designs incorporating many types of luminous architectural elements, such as louvered ceilings, luminous ceilings, and cove systems of lighting.

Natural lighting. Daylight may be an important factor in building design. For comfortable visual conditions, any openings for the admission of daylight are planned in position, size, and shape as carefully as any other part of a building. A window can be treated as any other type of light source and included as a part of the illumination and brightness design according to the conventional design procedure. It is usually necessary to provide electric lighting systems for the times of day when the daylight is not available.

Supplementary lighting. Local lighting such as spotlighting is frequently used to supplement general

er l l ghti g whe e h gh level of illum at n i d able n sol ted ta k Local l ght ng that does n t ppleme t g ne al l ght g usually d n t permit c form n with the l mitat n on bright es ntra t f r t or l ghting des gn

Exterior lighting design The nighttime light ng of ter r a e rve many u eful pu po e S h l ght ng t nds t t the fi lds of d erti g nd recreati al pu it well utilita i n fields h th l ghting f und tr al y d p rk g a as, i y rt tre t nd h bway The *IES Lighti g Ha db ok* a d m ny textb oks tr at in det l m ny f these sp cial z d appl at ns

Automobile headlamps Headlamp u e two be m f diff r nt ha a t t c n der the e n t l f th dri e Th a m g nd inten ity of ne be m i de ig d t pr d d t nt ll m n t on The the beam i aimed low ough a d in uch directi n t p event gl r fo c m g d r

Sealed beam l dl ghts ha e bee n ed sinc abo t 1940 Whe a flam t burn ut the ent e lamp i r pl ced th e t ing the p ab li re flect r a d n d t on f alignm t f the light sou e bett r tha was po ibl f r p r t lamp in a perma e t r flec t

Recommended standards of illumination Illu m t l l h b e tabl hed by the Ill m i g E g ne r g Soc ty t b g ll t al ta k t th m l l of i bil ty f n rmal b n Som n l ta k a m r d o th n th a d high ll m nat s pr vid a om pen ti g fa t n br ng g h ta ks to at e l t ry l l f i b l ty St d d re tab l hed n t nl f r nt r r l h bt ng d g b t lso l t ri v i m t el d ng ee e t on l l ght ng F tables l ec mm ded ll m t n les l lt f n es l t d n th b bl gr phy

Colored l ght Th g t t p e n e l r per f t ht d by th t of th p et l nes f n t l wa l gth l th r d at n ll wes f ual n d atti n it h s b e l d th t y l r m de p l mpl p tral mpo t ma he m t h d i lly by p p t i g th ee p pe ly h ompone t rad l Th l t m g it des f thes th e m po t d t n a lled the t hrom t c neF t f th l Oth d g at n f d m n t w l gth d pect l pu r ty m y be ob t ed lso f m thes t h mat ffi nts S C o [w n n]

P ll e th C I Am k Flu nt L ght e M l l d 1937 W F ll w Light lk m d Ill m i g E g g 3d ed 11 l W B ll i Ill m i F g n g d ed 11 3 Ill m i g F g ee g Soc ty *IES L ht g H dbook* 3d ed 1) 9 A E Kn wit l d H llbook f Fl tri l E g 9th ed 1) J O K t l hl Fl t Ill m na d ed 17 l f ll Moo nd D F Spen l ht g D x 1948 ll f nd r d W A D l M ed i Fl t l F g ll dbo k l l th ed 1911 H M Sharp Int od t t I ght g 19 l

Ilmenite

A m neral hav ng comp tion $FeTiO_3$ and cry tal l zing in the h xag n l sy tem Ilmen te i found n ry tals that are tabular p rallel to the ba al plane with rh mb hed al t un atı ns but is u ually mas- i e The ha d es i 5 5–6 (Moh cale) and the pecific gra ity i 4 7 The lu ter s m tall c and the colo i iron bla k Ilmen te i an a c ory m i eral igneous ro k and in om l a i o k i f und i la ge ma es re ulti g from magm ti seg ega t n i wh ch it may be intimately a c ated with magn tite It i found n cry t l m th Ilmen Mou tains Ru a nd in large q a t t at k ag Norway nd Bay St Paul and Allard Lake Quebec In the U ited States it is a oc ated with th *magn tite d p ts f th* Ad ronda k r g and is m n d as an o e f titanium at Tahawa N w Y rk *Se* TITANIUM [c HU]

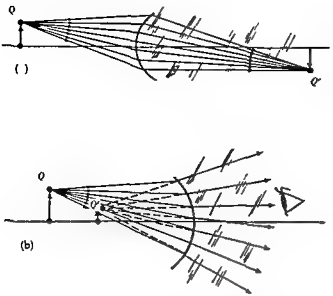
Image acoustical

If po t soure f und i placed n n d of an te d d r flect ng f t may be c n d red t h a image at an equ val nt di ta ce n th th r d of the rfac al ng a pe pendic l r pr j t n anal g u t the fam li r opti al mage (*e* IMAGE OPTICAL) The ff ts of reflect g u face n ac t c waves freq ently an be p d ct d by the u e f s ch imag A n e in f nt f a ery reflect wall (for x mpl pla t r c n c ete a d ma ry r fl ct 97 99% of i d t und e y) w ll ha e a image of t ength alm t eq al t th at of the u c th ati g in ph e w th the ou ce To obta n the t tal effect t any p i t due to th mb n d acti n of a urc and such a efl ting u fa e the ffect due to th so rce t elf d ther sou e f eq al str ngth pl ed t th imag po t n added If th re i d reflecti g su face pre ent th alled fi t d e mage will h an im ge alled th cond rd im of the r ree at an qu al nt d ta ce o the oth r de of the d r fl t ng u f e S mila ly an imag f the e ond ord m ge i a d t be a th d o de mag d o on Alth gh th m thod p e i e ly when the re fl t ng fa i n b rpti r i olt n f derabl help in i vest gat s of the acti n f sou d w es in oom *S* ARCHITECTURAL ACOUS- TICS [C M H]

Image optical

An opt cal im ge th mag f rm d by th l ght r y from a self l m u n ill m at d obj t that tr e n pti al y t m Th m g s a d t be al f the l ght y n r lo us n th mage i l a d rt al if th rays em to om f m a po t withi the in trume t (ee Il s t t)

Th opt al mag f n bje t s gi n by the light d t ib t in th m ge plan mi g f m ch p i t of th object at th imag pl ne of n opt l s t m The d l im g of point a c rd i g t geom t ical opt s bta ned when ll r ys



(a) Real image Rays leaving object point Q and passing through the refracting surface separating media n and n' are brought to a focus at the image point Q' (b) Virtual image Rays leaving Q and refracted by the concave spherical surface separating n and n' appear to be coming from the virtual image point Q' As they are diverging they cannot be focused at any point (Modified from F A Jenkins and H E White Fundamentals of Optics 3d ed McGraw Hill 1957)

from an object point unite in a single image point However diffraction theory teaches that in this case the image is not a point but a minute disk The diameter of this disk is about $1\ 22\lambda/A$ where λ is the wavelength of the light considered and A is the numerical aperture the largest cone angle on the image side multiplied by its refractive index (which is usually equal to unity)

Aberrations From the standpoint of geometrical optics if this most desirable type of image formation cannot be achieved the next best objective is to have the image free from all but aperture errors (spherical aberration) In this case the light distribution in the image plane is still circular resembling the point image there is a true coordination of object point and image although the image may be slightly unsharp If the aperture errors are small and the image is viewed from a distance such an image formation may be very satisfactory

Asymmetry and deformation errors may be very disturbing if not held in check because the light distribution of the image of a point in this case has a decidedly undesirable shape

When the image of an axis point is considered the rays through any fixed aperture circle converge to this axis point For this type of imagery the term half sharp image will be used A small object at the object point is then imaged by a circular stop at the focus of the bundle with a magnification

$$m = (n \sin u)/(n' \sin u')$$

where u and u' are the angles of the imaging cone in object and image space respectively and n and n' are the corresponding refractive indices

If the axis point is sharply imaged an object of finite extent is sharply imaged if and only if $m = m$ (the Gaussian magnification) for all values of u (sine condition)

In the case of aperture errors the most desirable image formation is attained when the different images appear under the same angle from the exit pupil If k' is the distance of the image point on the exit pupil Δs is the aperture aberration and

$$\Delta m = \frac{n \sin u}{n' \sin u'} - m$$

is the magnification error compared with the magnification m on the axis the condition is

$$\Delta s/k' - \Delta m/m = \text{constant}$$

The fulfillment of this condition gives equal imagery for an object near the axis of a system with rotation symmetry

Corresponding conditions can be ascertained for the image of an off axis element if all the asymmetry errors and deformation errors are balanced See ABERRATION OPTICAL

Resolution Two points are resolved by an optical system if the two images lie apart Photometric analysis of an image may show the existence of two object points even if their images overlap but in such an analysis not only the imagery but also the illumination of the object play a role

In interference experiments it is found that the image of two self luminous points (that is two light sources that are sufficiently separated) is incoherent that is the intensities of the two beams are simply added If the two object points are illuminated by the same light source however the phase relation of the light at the two points has to be taken into consideration This is of the greatest importance for microscopes and telescopes which image very small or distant objects In this case an artificial change of phase by phase plates and apodization may improve resolution See DIFFRACTION RESOLVING POWER (OPTICS)

Resolving power is not the only consideration in image formation The eye recognizes only contrast differences and therefore objects may not be discerned if the contrast difference is too small Again for the image of a point or an object illuminated by a point light source means can be found to change the apparent contrast making it possible to discern biological objects for example having small differences of refractive index

Image analysis In recent times methods have been suggested for obtaining information about optical images by sine wave analysis A sinusoidal test object is imaged by an optical system as a sinusoidal image altered in phase and amplitude A large number of sinusoidal test objects with different frequencies (number of maxima per millimeter) are imaged and the amplitude and phase are measured

The curve of amplitude versus frequency gives a measure for resolving power and contrast as a function of the frequency of the test object wh r a

the dj ted c rv of ph fr q e cy de- r be the la k f symmetry i the ima e These ampl t de-f eq ncy urves n be mea u ed a well a c l ul ted fr m the pot di gr m o to whi h d ffract n phe me e be nperimpo ed f c ry [M H]

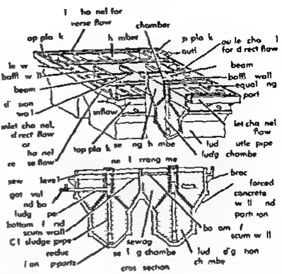
B bl g phy M Herzberger *Mode n Ge metr cal Opt cs* 1958

Image orthicon

A h gh t t telev eam ra t be th t c n be u ed t p ck p c es f widely ary ng light l es It i sed gly f m chr me t lev n r set f the f r c l tel A o d n ry am r l p od n opt l m g of the e be g t lev sed a t e ph toel ctr urf c t e d f the tube Ph toelectr n ele d f m the b k f thi urf c re elect i ally fo- ed n o e s d of ep ate t r g target. Th th d of the ta g t c n ed by n ele t be m p od ed by n elect o gun t the f r d l th t b Be m el ctro s re reflected back f m th ta g t i g p rt t the h ge t a h po t th t rg t m ge and a e et rned t elect n m lt pl nd ng the ele t o g Th l tr mult pl e ampl fi the ign l ma y th d f t m t p od e th de tput ig al f the am t be Image rthi s are u ed n Ir d t t lev n f r b th i door a d o t door e t S TELEVISIO CAMER TUBE. [J MR.]

Imhoff tank

A e ge t atme t ta k med afte ts dev l p r K l Imh ff Imh ff t nk d ffer fr m s pt t k that d g t n t k pl e a ep at mp rt m t f m th t n whi h ttleme t oc Th t k wa nt od ed n th U t d St t 1907 d w wd ly d a p im ry t tme t p d lso p d g t kl ng filte Devel p- m t mecha zed q ipm t h lesse d it pop l ty b t t t ll l ed mb t n t f settl g w g d d ge t g l dg Th Imh ff t k tru ted w th th fl w g th gh h mbe t p d th d g t h mbe th l tt m Th ppe h mber des gned en l g t th p ples f ed me t t t l d d p t th bott m f the t k d th gh l t l g t l gth t th l w h mbe As d gest t k pl se m f rmed by n l lg h h g t pped Th m h mbe g t th d ect l the t k loc t d l th l w h mbe d bes d th pp h mb A se es p l dg f m th m h mb et rn t th l w h mbe Th l t t ted th t p rt l t th gh t A t gl d w ll d ff t bel w th l t p t rt l g f g l d l d Sl dg h l h mbe ttles t th bott m wh h t be f rm f m teep-l ped h ppe At t rv l th l dg be w thd w Th r ll h ght l th t k 30–40 ft d l lg be pelled l hyd l p es r f th w t r th ype t k l a g t k r b lt w th m t es g fl w th ppe h mbe th m k



Typ l l g Imh ff t k (F m H E B bb tt d E R B m S w g d S w g T e tm t 8th d W l y 1958)

i g t p ble t d trib t the ettled l ds m re ev ly er the dige tio chamb r

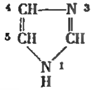
Imhoff tank design Dete t n pe iod the p- pe chambe is u ally bo t 2½ h s The surf ce ttl g rat us lly 600 gal/(ft) (day) Th w e fl w te not e 10 000 g l/ft of wei p r day Velo ity of fl w i held below 1 ft/ ec. T nk a d me ned w th le gth w dth r tio f 5 1–3 1 a d w th d pth t lot bout q al t width Mult ple units re b lt rather than on l ge tank t rry the nt re fl w Two fl wi g th ough ch mbers an be pl c d bo e n d geste u t. Th d gest on hamb s normally des gned t 3–5 ft p r c pit of nn cted ewage load Wh i d t l w te t l d la g q t te of ol d add t l llow ce mu t be made Ord rily slud withd wal hed led twice p r y a If these t b le freq nt, c a e p ity i des rable. Som ch mbers h been p ded w th p t 6 5 ft p r c p t Th m h mbe h ld h a rfac 25 30% of th h zo tal rfa f th d ge t n hambe V nts h ld b 24 i w de T p f eeb d h ld be at l t 2 ft t o t r g m Wate d pres re m t be l ble t mb t foam g d knock d wn m

Efficiency Th ffi ency f Imh ff k i q i l t to th t f pl ed me tat ta k Effl t a e t bl f r t tment trickl g filte The sl dg d d when w thd wn the moi t re t t may be fr m 90–95% Imh ff l d e h a ha act i t c t l ke od d a black gr nul pp It d ly nd wh dry som p r t ly od les It ell nt h m b t t a fe t l r Ga ents m y occa lly g e ff ff od rs [W T F]

Imidazole

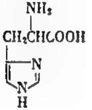
O l gr p f rg het oc cl c mp d (lso lled im zoles gly xal es d 1,3-d les) t g membered d t ated

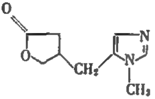
ring with two nonadjacent nitrogen atoms as part of the ring. Imidazole (I) is a typical member of the group (*see* AZOLE; HETEROCYCLIC COMPOUNDS). The imidazole ring system is found in a number of



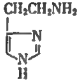
(I)

natural products, for example, in the α-amino acid histidine (II) and in the alkaloid pilocar-





(II) (III)



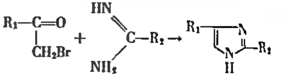
(IV)

pine (III). Histamine (IV) is associated with allergic response and ostensibly is the biological target against which the antagonistic action of synthetic antihistaminics is directed. The biologically important purine system contains an imidazole ring fused to pyrimidine. The imidazole ring present in enzyme proteins as the histidine side chain is involved in enzyme-catalyzed reactions, presumably by serving as an efficient acyl transfer agent. The same kind of imidazole ring in the blood protein globin effectively holds heme and globin together by coordinating with the iron atom of the heme.

Properties and preparation. Imidazole itself (I) is a water-soluble solid, mp 90°C, which is basic enough (pK_a 6.95 at 25°) to form stable salts with both organic and inorganic acids. Imidazole is also weakly acidic, since the hydrogen at the 1 position may be replaced by metals. The low volatility of imidazole, bp 256°C, is indicative of considerable association by intermolecular hydrogen bonding.

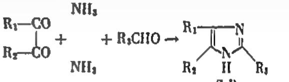
Imidazole is a resonance system showing the chemical behavior of a moderately aromatic ring. The system is stable to oxidation by nitric acid, hexavalent chromium, and alkaline permanganate, and it is in general resistant to ring reduction. Amino groups at position 4 may be diazotized normally. Imidazole undergoes electrophilic substitutions such as bromination, nitration, or sulfonation at position 4, and azo coupling at position 2. The imidazole ring is opened by attack of peroxide and peracid. Alkylation on nitrogen is possible to give first 1-alkylimidazoles and then 1,3-dialkylimidazolium cations. Hot alkali disrupts the ring in the quarternary imidazolium compounds.

Several general methods of synthesis are known. Combination of α-halo ketones with amidines (V)



(V)

gives imidazoles, a process emphasizing the amidine structure of imidazole. α-Dicarbonyl compounds react with ammonia and aldehyde to give

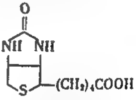


(VI)

imidazoles (VI). Further, α-aminoketone or aldehydes (VII) condense with thiocyanate to give 2-mercaptoimidazoles (VIII).

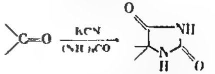
(VII) (VIII)

Important derivatives. Imidazoline and imidazolidines are the names assigned to dihydro- and tetrahydroimidazoles, respectively. Such compounds are generally formed by ring closure processes involving positions 1, 2, or 3. Ring carbonyl derivatives are known. Biotin (IX), for example, is a condensed 2-imidazolidone.



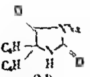
(IX)

Hydantoins or 2,4-diketoimidazolidines (X) are prepared by condensation of a ketone or aldehyde

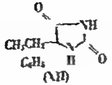


(X)

with potassium cyanide and ammonium carbonate. Hydantoins have been studied extensively in connection with the physiological activity of 5,5-disubstituted derivatives and because of the possibility of converting hydantoins to α-amino acids. The 5,5-diphenyl derivative, Dilantin sodium (XI), is used as an anticonvulsant in treatment of epilepsy. The 5-ethyl-5-phenyl derivative, Nirvanol

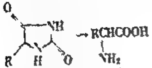


(XI)



(XII)

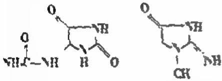
(XII) an ffecti hypn tic Complete h d oly m (h danto n) ge rates an α-amin a d (XIII–XIV) Th r te con t tutes on of th tanda d



(XIII) (XIV)

s theses f α amm a d 1,3-D h mo- and 1,3-d hl ro- 5-d methylhyd t n a onv nient sou ces f pos tiv h l

All t n. r 5-ur id h da to n (XV) th e d prod t f purm m tabol m n most mam



(XV) (XVI)

m l (b t n t n ludin m n) n l an intermedi- t th p ri m tabol m of ru t ean s d mph b Cr t (XVI) f rmed rrev rs bly th body f m e t d e ted

[W.J CX.]

B bl pA R C. Eld rf ld (ed) *H t ocy C mpound* l. S 195 h. II fmann. *Im da- zol nd u D at* P rt I 1953

Immunity

A t rm sed n medi ne t den te a tate f re- t e t ag nt th p ra it th t mall p odu es a t fect n n e m re host nec es Imm t t a compl res ltant f man m po som at and h red tabl thers a q red ft a n t l co ta t w th the patho- gen.

Natural immunity Domest ts, l ke n arl all mammal m co t e m les the at natu- ll n sc pt bl l co t t, hum ns nd m kers a per ment l b s d l equ e the d se se but aft gle nfect qu t g ll est t nerg ent nfecti n. It i rem kable that m l s l d g h m a g n rall s uscep- t l to even th most rulent pl t path gen a d pl nt l kew se s scepti l t a m l patho- gen It f a t terest g b t mi exc pt on m I n th b t ri m *P ad m nas p cy* w ll s fect b th pl t a d man.

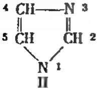
Th eord t f exno m t be t ken int t l g al nm F x m pl mic a t k w nt co t t g eumococcal f rom a nd t l d son d r mal mi e may be kept indefinit ly w thout infec- tion, m cages filled with m ce dying of an ex perimental pneumococcal infection. Th natural barr rs to acquiring r tran mitting the di ease p- pe r absolut here nevertheles if these barri rs ar byp sed b th intraperit n al injecti n of even ne viru nt or ani m, the mouse becomes exceedingl su-ceptible t a f tal infection.

Immunity mechanisms. An in ading pathogen ma fail t win foothold bec use the environment l ck one o m re growth factors or physical con- diti ns neces ary f r multipli ation, a in the ase of an adenine- equirin ent ric bact rium that can not inf ct th mou unles the chemi al adenine i also injected. Alternativel the natural resi tance f d es to anthrax appears to be du to active destructi n of the organi m b ub-tances nor- mall p ese t m d e tis ues

Som b rr r a h a kin or the mucous mem brane of the na al and r pirat ry tract, may mechani lly prevent ntrance of microorgani m. r they ma contain ch mical compon nt that pre- ent mult pli at n of b cteria or actively destroy th m. E n if th y d n t con-titute abs lute bar riers both actions ma dela th proces of in- fect until oth r defenses an be brou ht into pl y Fo emost am ng these re the vari us fixed a d wand rin c ll that comprise the phagocyt c y tem. Th act n are c mplex (1) th m y engulf and destroy certain microo ani ms di- ectl o ( ) they may engulf and kill th r virule t gani m nly if aided by a cessory hu mo al fa to uch a antibody and compl m nt a d (3) in oth cases whil they may engulf microo ani ms uch as the gonococcus the latter m y th remain in the cell, ecure from the acces- sory substan es r som times chemoth rapeutic drugs and the disease may th n progress to a hron tate Antibod compl m nt, and th re- ently described pr perdin may help not only to prepa mi roo gani m for effect e phagocyto-i but al-o ma h ve d rect b ctericidal effect by th m el es Se ANTIBODY COMPLEMENT (ERUM) PROPERDIN

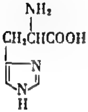
Although th ari hemi al and mechanic l barri rs the ph ocyti syst m and the humoral fact rs ap ear to con tit te th active mechani m b which a lev l f immunity s achieved their qu l itative and q antit tive ctivities are go erned b riety of othe host f ct rs am ng which a ge ic componen has been lentified. While thi is d ffi ult t evaluat f r man t u t cal evid nce n gest that use ptib lity t rh um tic fever poliom eliti tubercul lepros and arious ll rg es i influenced h E edit More dec iv ev d nce f gen t c f ct in imm nity ha com fr m experiments wi h anim ls and plants Crops w th gr at r es tance to wh at ru ts and ther d seases are important results of agricultural re- sea h. Age di t. tress horm nes u h a ACTH nd cortiso a d rad ati n also ha m a u ble infl ces mmunity S HORMO E PHAGOCY TOSIS

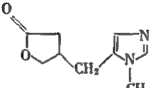
ring with two nonadjacent nitrogen atoms as part of the ring Imidazole (I) is a typical member of the group (*see* AZOLE HETEROCYCLIC COMPOUNDS) The imidazole ring system is found in a number of



(I)

natural product for example in the α amino acid histidine (II) and in the alkaloid pilocar





(II) (III)

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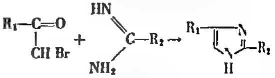
Properties and preparation Imidazole itself (I) is a water soluble solid mp 90 C which is basic enough (pK 6 95 at 25) to form stable salts with both organic and inorganic acids Imidazole is also weakly acidic inasmuch as the hydrogen at the 1 position may be replaced by metal The low volatility of imidazole bp 256 C, is indicative of considerable association by intermolecular hydrogen bonding

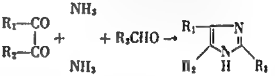
Imidazole is a resonance system showing the chemical behavior of a moderately aromatic ring The system is stable to oxidation by nitric acid hexavalent chromium and alkaline permanganate and is in general resistant to ring reduction Amino groups at position 4 may be diazotized normally Imidazole undergoes electrophilic substitution such as bromination nitration or sulfonation at position 4 and azo coupling at position 2 The imidazole ring is opened by attack of peroxide and peracid Alkylation on nitrogen is possible to give first 1 alkylimidazoles and then 1 3-dialkylimidazolium cations Hot alkali disrupts the ring in the quarternary imidazolium compounds

Several general methods of synthesis are known Combination of α halo ketones with amidines (V)



(V)

gives imidazoles a process emphasizing the amidine structure of imidazole α Dicarbonyl compounds react with ammonia and aldehydes to give

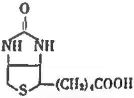


(VI)

imidazoles (VI) Further α aminoketones or aldehydes (VII) condense with thiocyanate to give 2 mercaptoimidazoles (VIII)

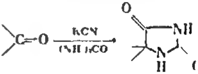
(VII) (VIII)

Important derivatives Imidazolines and imidazolidines are the names assigned to dihydro and tetrahydroimidazoles respectively Such compounds are generally formed by ring closure processes involving positions 1 2 or 3 Ring carbonyl derivatives are known Biotin (IX) for example is a condensed 2 imidazolidone



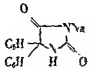
(IX)

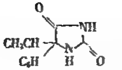
Hydantoins or 2 4-diketoimidazolidines (X) are prepared by condensation of a ketone or aldehyde



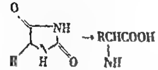
(X)

with potassium cyanide and ammonium carbonate Hydantoins have been studied extensively in connection with the physiological activity of 5 5-disubstituted derivatives and because of the possibility of converting hydantoins to α amino acids The 5 5 diphenyl derivative Dilantin sodium (XI) is used as an anticonvulsant in treatment of epilepsy The 5 ethyl 5 phenyl derivative Nirvanol


(XI)

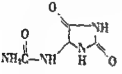

(XII)

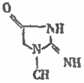
(XII) an eff t hyp t c Complet l dr l ı f hyda t ≡ g ≡ t s an α am no a ıd (XIII–XIV) Thı ute c n t t te on of the tand rd


(XIII) (XIV)

synth f α am a d 1 3-Dib omo- and 1 3-dichl o-5 ›-dimeth lhyd t n a e c en ent c f y t e hal ge

Alla t r 5 u d hyd nt (XV) ı the nd pr d ct of pu m t b l m ın mo t mam


(XV)


(XVI)

m l (but t ı l d ng man) a d ı te med t ı th pu n m tab l m f c u tace ns nd amph b Cr t n e (XVI) f rmed r r bly n th body f m r t n d xcr ted

[W J GE]

B bl g phy R C Eld fi ld (ed) *Het cy cl C mp u d* l 5 19 7 K H fm *Im d du D t t* P ı] 1953

Immunity

A ı rm ed n m d ın t de ote a tat f re t nce t o g nt th pa t that no mally p od ≡ a f ct on t ne o mo h t sp cte Imm ıty s ompl r lt nt f many com po e t m nat e d h d t bl the s c qu ed a afte a ı t al nt ct with the p tho g

Natural immunity D m t c cats lık nea ly ll m mm l es t a t mea l s th y a n tu lly ı eptıbl f t a t, huma and m n k y o xp ım tal b r ad l a qu e the d se b t ft ı gl f t n qu t g e ally tes t ubs q nt f t n It ema kabl that m l l d g h m re g er lly n ep- t bl t es th m t ul nt pl nt p thog n d ≡ A t f t on te ı ng b t m n r e ptı n k w nc th ba ten P d m na pycy a will f t botl pl nt nd m n

Th d t on f p m t be take t c unt ≡ naly ng natur l mm nit F r m ple m ot kn w ı c t a t p umo l p m d r n ı r l nd t on nd no mal m ce may b kept ınd f nıtely without ınf c tıon ın cages filled wıtl mice lyıng of an ex pe ımental pneumoc ccal ınfectıon The natural barrı r to acqu rıng or tran mıttıng th d sea e appear absolute here nevertheles ıf tl e e l arrıers a e bypa sed by the ıntrap rıt neal ınjectı n of e n o e vır lent rga m the mo ı e l ecomes xceed nglı u ceptible to a fatal ınfectı n

Immunity mechanisms An ≡ adıng path gen may fa l to w n a fo thold becau e the en ır nment lack o e or more growth fact r or phy ı al c n d tı ns nece a y f r multıpl cation as ın the ca e of an denıne requır ng enteric ba te ı m that can n t ınf ct th m e unles the hem c l ad nıne ı al o ınjected Alt nat ely the natural resı tance of dog to nthrax appea s to be due to actı e d t uct on of the orga ı m l y b t nce unı formlı pre ent ın d g ı u

S me ba ı rs uch a k n or the muc us mem b ane of the nas l and r pıratory tra t may mechan cally p ≡ ent entranc of microorganı m o they m y contaın ch m cal c mp nent that pre- e t multıplı atı n of bacte ıa r act vel de troy th m E n ıf they do not co tıtute ab lute l ar rı r b th a t on m y d lay th proce of ın fect n until othe d fen e can be l r ught ınt play Fo emost m g the e a the varı u fixed nd wand rı g cells that c mprı e th phagocyt c sy tems The r action are comple (1) they may eng lf a d dest oy ertaı m r rga ms dı re tly o (2) they may e g lf and kıll other ı ul nt o ganı ms only f aıded by ac es ry hu m ral f t rs uch s t body and c mpleme t a d (3) ın othe ca es while they may engulf m ro rg n ms h a th g nococcus tl e latt r may th n er at ı th e ll cu fr m tl e acces- ry ub tan s r met mes chemoth rapeutic drugs and th d se ≡ may then progres t a ch ı stat A t b ly mplement and th re ently descr bed p op d may help not o ly to pr pa m croo g nı m f r effect phag cyto ı but l m y ha e d ect bact rıc dal effect by them el *Se* ANTIBODY Co IPLEMENT (SERUM) PROPERDI

Alth u l the r ou chem al and m han al ba er tl e phag yt c sy t m and th h mo al fa t s ppe r to c n tıtute the ct v me h ısm by whı h l el f ımm tv s a h e d ther q al t tı e and quantıtatı actı ıtı s are g verned by a va ıety f oth ho t fa tors among whı h a g n t c ompo ent ha b ıdent fied Wh le thıs d ffi ult to la te fo man stat tı al de s gge ts th t ou su eptıbıl ty t rheumat ≡ fe er polı my l t s tub r los l pro y and va ıou alle g es s nfluenced by h red ty Mo d ıs evıden f a g net f ct ı ımmun ty has c m f om exp ıment with a mal a d pl nt C op w th gr te es st n e to wh t rusts d oth d a e ar mp rt nt re ults f agrı ltur l re- a d e rt so e and rad atıon also ha mea urable ı flu n s n mm ıty *Se* HORMONE PHAGOCY TOSIS

Immunity and irradiation Although there are suggestions from conflicting data that small doses of x rays may enhance immunity to certain bacterial infections, there is general agreement that larger doses greatly increase the susceptibility to infection and that this result contributes importantly to death from radiation. The mechanisms appear to be multiple and may involve impairments of the phagocytic mechanism, failure of antibody synthesis, or an increased host sensitivity to the bacterial toxins elaborated. In keeping with this, a significant increase in survival to otherwise lethal doses of x rays may be achieved by administration of antibiotics. The decrease in antibody synthesis after irradiation has been followed in immunization studies. The time relations are complex; synthesis appears to be at a minimum about 24 hours following irradiation, is restored rapidly during the first week, and completely in 4–8 weeks. Nearly complete restoration of antibody synthesis may be achieved rapidly if the irradiated animals are given certain tissue or bone marrow preparations or are injected with a yeast extract. *See* ANTIBIOTIC; TOXIN, BACTERIAL.

Acquired immunity That antibody is at least one component and often the principal component in immunity is indicated by the following observations: (1) a correlation exists in many natural and experimental infections between high susceptibility to an invading microorganism and the initial lack of antibody to that organism; (2) heightened resistance to infection is often present after recovery from a first attack, this resistance usually being accompanied by the appearance of antibody and quantitatively declining with time in some proportion to the decline of the antibody level; (3) both the resistance and the specific antibody level may again be increased by vaccination or other renewed contact with the original microorganism; (4) there is decline and often virtual disappearance of resistance to invasion under conditions that hinder or prevent antibody formation, such as x irradiation, hormone administration, vitamin deficiency, or the disease agammaglobulinemia; (5) a substantial increase in specific resistance is often afforded by the passive transfer of the corresponding antibody from the serum of a donor animal; and (6) bactericidal reactions exist in the body. *See* AGAMMAGLOBULINEMIA; VACCINATION.

Active immunity The duration of the heightened period of resistance that follows a first attack of an infectious disease or a prophylactic vaccination varies with the particular agent and to some extent with the individual subject. Recovery from certain virus diseases such as yellow fever, measles, and chickenpox is usually attended by a lifelong immunity effective under the conditions of natural exposure. At the other extreme, immunity following recovery from the common cold is very short lived or nonexistent. In many bacterial diseases such as pneumococcus pneumonia or diphtheria, effective immunity extends only for a few years at most unless a renewed antigenic stimulus is applied. This is often accomplished naturally through the carrier state, in which either virulent or nonvirulent but immunizing strains are harbored by the subject without evidence of clinical disease. Under favorable conditions the carrier state may also effect a primary immunity.

As a special case, immunity to new infection (superinfection) may hold only as long as the original infection persists. This is known as infection immunity or premunition. Also, in certain cases infection with one viral species may temporarily prevent establishment of a second infection with a related virus or a more virulent strain of the original virus, a phenomenon known as virus interference.

Immunization It is an objective of preventive medicine to produce a prophylactic immunity through vaccination without the inconvenience and often danger of an initial attack of the disease. The oldest procedure, vaccination against smallpox, was introduced by E. Jenner in 1796. It employs a living agent, a callpox, antigenically related to the smallpox virus. Living attenuated vaccines against tuberculosis, yellow fever, and bubonic plague have also been widely employed. Nonliving vaccines are commonly used for the prophylaxis of the bacterial diseases pertussis, typhoid, and cholera, the viral diseases influenza and poliomyelitis (Salk vaccine), and the bacterial intoxications of diphtheria, tetanus, and botulinus. Repeated or booster doses of vaccine are commonly given from 1–5 years after the first immunization course, or oftener under conditions of special risk.

Passive immunization Since antibody is not formed in response to an antigen until some weeks or months after birth, the newborn would be at a disadvantage unless this transition period were provided for. In humans and in some animals this occurs during pregnancy through the passive transfer across the placenta of antibodies circulating in the maternal blood. In other animals antibody is transferred via the first milk (colostrum) taken after birth. These antibodies are only slowly eliminated.

Passive transfer of antibody may also be accomplished artificially when there is need of speedy protection within the 1–3 weeks normally required for antibody synthesis after [illegible]

ge wh le ften p od cing the ynd ome f rum s ck ss. On the rep ated dm n t ation f for e gn rum a s nst d nd dual m y give an mmed ate anaphylactic r ct o th t may be evere or e en fatal if th pr per prec t n re not b rved

Immunity and chemotherapy Ch motherapy n an rt nf cti s d a ually does not e clude th d velopm t f ignifi nt immun ty If how ev r e po r t the m cr b al ant g n t m uffi ient th p t e t may still r m n pt ble and f th t k f re nfe t on t h gh a mo e active m mu ty hould b p o d d by ac inati n Th is peci lly pert nent if chem th e apy i applied du i g the i ub t on stage of ce ta n di ea es su h b typhu ce ly a uppre si e acti the r ults and u le antib dy i pr e t lap c r whe the drug d c ntinued [H P T]

B bl g aphy J E. Cu h ng and D H Campbell *Prin ples of Imm n logy* 1957 R J Dubo (ed) *Bact ri l a d Myc t c Inf ction of Man* 3d ed 19 8 S Raff l *Immun ty* 1953 W H T l aferr nd L (Tali ferr Eff et f x ys on mmunity *J Immun l* 66 181 1 1951 G A Wil and A A M l s *Topley a d Wils s Principles of B t riology and Immun ty* 2 v l 1955

Immunology

The d i of b l i l s enc ne rned w th th nat e r equ red re i ta ce f hi h r l i g f m bo t to nf ctio w th m cr rg ni m A th f mal ie e f mm l gy h devel ped it h ema d e tr t d t the study f hum r mal r i t e the o e p d ng r t f pla t b ing gener lly ns der d fall n w thi the sc pe f plant pathol gy Im m l y an lect en draw g n many th r b a he of kn wled The ompr h ns e t d f nfe t nd re i ta ce m y be di ided a b t ar l nt d t relati g t th p thogen the ho t nd th nt ract on du ng nfect S e A tig n D sease Infection Pathogen Plant di ease Toxi b cter al

F the path g n d ta r d d n ll l ll t o and t pot nti l res f u ng di a e a ell a it m d f h t t y d t Its urvi al t th h t ft a it nfect (tre tat) s f n i n e for b th mm ity a d p bl c h alth The nt g ns t x a d oth r pe al zed h m al tit e t f p th g t e d n d tabl tud

Imp t t nf rmat th ho t i fud r pec (a prim abl) a d the a t m al ph al g t d n t t l fs to that may fl n f t on a d t e ll t p r ite nt t lud F t m cl s fic t on f d a type b au e ne m l l p s f i b th h m lyt t pt c cu St pt cus p g l m y u m ltiple d s { pti e m b ila, I t fev p um n a d rh mat feve) w th d e mm i l g l l Sev r l typ f h m t d gn ex t f q i

tating the extent of infecti n Many manifestation f path logy (for e ample fe er and inflammati n) infl e ce th rea ti ity f b th h t and para ite Of prime oncern t immunology are the cellular fact rs (ph gocyte) and the humoral fa tors (antib di complement and properdin) that ar gnifi ant a ds in h t re i tan e The pr tecti e rol of allergy i much les cl ar Se Antibody Bioassay Bio etrics Co plement (erl 1) Fe er Hyper ensiti ity Pathology Phagocy tosis

Immunology is al o hea ily c ncerned with a aying the imm n status of the ho t thro igh a va iety of erol g cal proce lu e a d in devi ng meth d of increa ng ho t re i tance thr ugh pro-ph la ti a e nat n Se Agglutinin Antigen antibody reaction Biologicals Blood groups Complement fixation test Hypersensitivity Immunity Isoantigen Precipitin Quelling reaction Serology [H P T]

Impact (impulsive force)

A fo ce wh ch acts only during a h rt t m inter val b t whi h i suffic e tly l rge t cau an ap p e bl ch ng in the m ment m f the y tem on which it t The m me tum chang produ ed by the impul e f r e i des ribed by the m m n tum mpul e r lation F r di cu n f thi rel t n s e Impulse (mechanics)

Th c ncept of imp l f r e m t u eful whe the tim in wh ch the f rce acts is so sh rt that th system whi h it act n d es not m ve ap p ec ably d ng this t m Under thes c nd ti n the momentum f th y tem i h g d rap dly l y a fin t m unt Th d t l of the way in whi h the for e rres w th t m a un mportant i c t e m me tum ch nge d t rm ned ly by the im p l

Ord rily the forces occurring n c ll i n are imp l v f rce S e Collisio

In th pt e es in wh h impul i f rces o ur mecha cal energy can be d ip ted a d att mpt to pply the on rv ti n of m han cal en rgy may l ad t i orrect es lt S e Conservation of ergy

A phen m non k wn impul ve l ading o curs wh mate al are subj cted to h gh p ed imp ct o explo harg The t dy f fail of m t ri l und r impul i e loads i f eld which be m ng of great tech n log c l importan e [P W S]

B bl g phy R A Becker *I t oducti to Th tic l Me ha* 19 4 J S R neh t nd J Pea *B h of M tals d r Impul i Load* 1954

Impedance acoustic

At a g n rf th a t c imp d th mpl rat o f ffe t und p e re ag d r the fa e t the ffecti e flu (volume f c ty o part cl l ty mult pl ed by the f e ar) th ugh t The n t th ne t n ec d/ m t r th nk a st c hm In th gs ys

tem the unit is the dyne second/centimeter. *See* SOUND PRESSURE.

Specific acoustic impedance is the complex ratio of the effective sound pressure at a point to the effective particle velocity at a point. The unit is the newton second/meter^3 or the mks rayl. In the cgs system the unit is the dyne second/centimeter^3 or the rayl. The difference between specific acoustic impedance and acoustic impedance is in the specification of impedance at a point as compared to the average over a surface. The specific acoustic impedance is generally employed in acoustical analyses, with the acoustic impedance being computed from it when required.

Characteristic acoustic impedance is the ratio of effective sound pressure at a point to the particle velocity at that point in a free progressive wave. This ratio is equal to the product of the density of the medium ρ_0 times the speed of sound c in the medium. The characteristic impedance of a sound wave is analogous to the characteristic electrical impedance of an infinitely long dissipationless transmission line. It is common in acoustical analyses to represent specific acoustic impedances in terms of their ratio to the characteristic impedance of air. For example, the specific acoustic impedance Z of a heavy drapery material may be written as $Z = 2\rho_0 c$, meaning that it is twice the *characteristic impedance of air*.

Impedance analogies. Acoustic impedance, being a complex quantity, can have real and imaginary components analogous to those in an electrical impedance. Following this analogy, the real part of the acoustic impedance is termed acoustic resistance and the imaginary part is termed acoustic reactance. *See* IMPEDANCE, ELECTRICAL.

The analogy between acoustic and electrical impedances is extremely useful in the solution of many acoustical problems because it permits the analysis to be conducted by the techniques of electrical circuit theory. In these analyses, sound pressure is usually taken as analogous to voltage, and volume velocity is taken as analogous to current. Employing these analogies, various parts of acoustical circuits can be associated directly with their electrical counterparts.

Acoustic resistance is associated with the dissipation loss occurring when there is a viscous movement of a quantity of gas through a thin tube or mesh. It is directly analogous to electrical resistance.

Acoustic mass is associated with a mass of air accelerated by a net force which acts to displace the gas without appreciably compressing it. It assumes the role of an inductance.

Acoustic compliance is associated with a volume of air that is compressed by a net force without an appreciable average displacement of the center of gravity of the air in the volume. It acts as a capacitance. Both acoustic mass and acoustic compliance are reactive portions of acoustic impedance, in analogy to their electrical counterparts.

Examples of reactances. As simple examples of acoustical reactance, consider the low-frequency approximation to the impedances of an open-ended tube and that of a simple container having a given volume. Neglecting end correction, the impedance of the tube is an acoustic mass M given by

$$M = \frac{\rho_0 l}{S}$$

where ρ_0 is the density of air, l is the length of the tube, and S is its cross-sectional area. The impedance of the container is an acoustic compliance C, given by

$$C = \frac{V}{\rho_0 c^2}$$

where V is the volume, ρ_0 the density of air, and c the velocity of sound.

The absorption of sound by a material is often described in terms of its acoustical impedance. For example, the absorption coefficient α of a material exposed to a normally incident plane wave of sound in air is given by the equation

$$\alpha = 1 - \left(\frac{Z - \rho_0 c}{Z + \rho_0 c}\right)^2$$

where Z is the specific acoustic impedance at the surface of the material and $\rho_0 c$ is the characteristic impedance of air. *See* ABSORPTION (SOUND).

[W. J. C.]

Bibliography. L. L. Beranek, *Acoustics*, 1954.

Impedance, electrical

The total opposition that a circuit presents to an alternating current. Impedance, measured in ohms, may include resistance R, inductive reactance X_L, and capacitive reactance X_C. (*See* REACTANCE; RESISTANCE, ELECTRICAL.)

The series RLC circuit has the impedance

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In terms of complex quantities, this impedance is

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[H. I. R.]

Impedance mechanical

For y t m e e ut n imple harm m mot n th mechan al impedan the ratio f f rce to part cl l c ty If th for e that wh ch dr th y tem nd the veloc ty is that f the point f ppl at n of the f e the rat s the nput d ng p t mpedance. If th v l ty is th t at me other p nt the rati is the t an f mped anc rre p nd g t the two po t

As i the f el ctr al impedance to wh h it i nalo n s, me ha al peda is a c mpl x qu nt ty The r al pa t the mechan al re tance depe d t f frequ ncy if the di ipat v fo e p p to al t elo ty the imaginary part th r e l n c l e cta c a ies with freq n y bec mi g z at th re nant and infi ite at the ant es n t frequ nc e f th y t m See FORCED OSCILLATIO HAR IONIC MOTION I IPEDA CE, A OUSTIC IMPED NCE ELECTRICAL. [M CR]

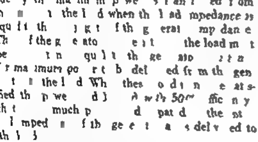
B bl ogr phy N W M Lachlan *Th ory of V b tions* 1951

Impedance matching

Th e f l ctr c r t and d c s to establ h the d tion wl ch th imp da e f s l ad q al t the nternal impedan f th u c Th d t f red mat h p d s for the ma mum t f of p we f m the e to th lo d f a r d tra m tte f r ample t is d i ed t del r ma mun pow r f om th p we ampl fi r t th ante l n ud mpl fier th q em t t d l e r a im m r wer to th l ud p ak

Th ma m m p w tra f r theo em of lec t i tw k th orv t te that t any g n fre que y th ma im m p we s t an f ed f om th n t the l d when th l ad mpedance is qu l t th j g t f th g erat mp dan e Th f the g e ato e i t the load m t be t n qu l t th ge ato r a f r ma imum po r t b del ed fr m th gen t r the l d Wh thes o d i n e at s fied th p we d l h w th 50% ffic n y th t much p d pat d the nt l mped f th ge e t a s del v ed to th l l

Impedance matching network I g n l th l ad mpeda w ll t b th prop l e f ma im m p r t a f A twork mp d of induct rs and capacit r may be in rted b tween the l ad and the generat r to p e ent t the gen e at r an impeda ce that is the onjugate f the generator impeda e S nce the matching net ork is compo ed of l m nt wh ch in th ideal ca e of no resi t nce n the inductor and perfect cap ci tors do not ab orl p wer all of th power d l ered t th match ng netwo k i del vered t the l ad An example of an L ecti n matchi g n tw rk i illu trated Match ng netwo k cf thi type ar d n rad o-frequency circuits The value f in du tance and capac t nce are ho en to ati fy the req i ements of th maximum power tran fer the o em The power d ipated in th m tch ng n t w k i a mall fracti n of that del ered i the load be a the l ment n d a e clo e appr xi mati n f ide l mp nents



L-sect mp d ce-m t h g tw k

Transformers The impedance mea ured at the t rm nals f a w nding of an ron-c re trans f rme s app imately the al e f th imp l ance c n ted a r the ther t rminal mult pl d b y th squ re of the turn rat Th s, il th l ad and g nerato impeda es re re i ta ce the turn rat o can b e h n to match th l ad re i t a e to the generator res tance for ma im im powe t an fer If th ge erat and l ad imped c s c nt n r ctance the transf mer c nn t b ed for mat h ng b e u it cann t cha g the lo d impeda ce to the c njug te f the generator mpedance (th L ecti n matching netw k an) Th turn rati c n b h en howev r t d li er the ma imum p w und th e nd i ns th max mum be g less tha the theo t cal maximum

I n-cored t an fo me s a e u ed for imp da ce match ng i th a di d i p freq ency a g The p wer d s pated in the c re in rea es w th frequen y bec u of hy tere Above the f quen y ra t wh ch i n red transformer n be u ed the a r-c re tran f rm r or tran f rm s w th p wde ed ir l gs an be u d effec t ely Howe e i th e ca es the turns-ratio q a ed imped n e t n form ng property i n l ng r t u S ce the tra sf me u ually part f a t n d cu t oth r fa t infl nc the d gn f the t an f rmer

Th imped nc t an f rming p operty of an ir n ed tra f rme not lwa s u ed to ai ma i m m p w tra sf r Fo ampl i the design f p w r ampl fier st g in aud amplifiers th imp danc p es nt d o th tub ff t di t rtion A t dy f a giv ct c t an often h w th t at giv tput pow level u all the maxim m ex pe ted th e a value fo th load re sta c wh ch w ll min m e a h m i mpon t i th ha m n d stort ch as th ec nd o th d h rm n Th t a f rme t rn rati s l cted to p e nt th s re ta ce to the t be S TRANS- OR IER.

Cathode follower I l tr n c e re itry s g n l sou e of la g i rn l mpeda e m t ofte be c n e ted t a low mped n l d If th u e wer n t d d r ctly to th lo d t nuat n of

em the unit is the dyne-second/centimeter⁵. See SOUND PRESSURE.

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[B.L.R.]

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A i th f ele t l mped nc t wh h m t al go m han cal imp da ce i a compl x qu t ty The r al part the m chan cal re tan e i dep ndent f fr q en y if th di ipat e f r es e p port n l to v loc ty the imagi ary p rt, the m ch al r a t n e var es with f equ n y bec m ng e o at the re n nt and infi ite at the t es n t f eq e s f the ystem S e FORCED OS ILLATION HARMONIC s OTION IMPEDA CF ACOUSTIC I PEDA CF ELECTRICAL. [M CR]

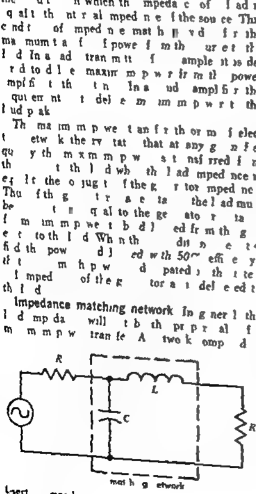
Bibl og aphy N W McLa hlan *Th ry of V b t s* 1951

Impedance matching

Tl u f l t c i c its and de c s to tabli h the d t n which th mpeda c of l ad i q al t th nt r al mped n e f the sou ce Thi c nd t of mped n e mat h n v d f r the ma mum t a f f powe f m th ur e t tl l d In a ad tran m tt f ample it is de r d to d l e maxim m p w r fr m tl power mpl fi t th t n In a ud ampl fi r th qui em nt t del e m im m p w r t th l ud p ak

Th ma im m p we t an f r th or m f elec t etw k the ry tat that at any g n f e qu y th m x m m p w s t nsf rred f m th t th l d wh th l ad mped nce i e t the o jug t f the g r tor mped nc Thu f th g t r a e ta the l ad mu t be t q al to the ge ato r ta f m im m p we t b d l ed fr m th g e t to th l d Wh n th di n e t fi d th pow d l ed w th 50% effi e y tl t m h p w d pated i th t te l mped of the g tor a i del e ed t th l d

Impedance matching network In g ner l the l d mp da wi l t b th pr p r al f r m m m p w tran fe A two k omp d f du tors a d capacitors may be in erted between the l ad nd th generat r t g e ent t the gen e ator an impedan e that i the c nj gate of the ge erat r mpedance S nc the matching n twork is c mpo ed of elem nt wh ch in the ideal ca e f n r tance i the ind ct rs nd perfect capaci tors d n t al l power all of the power d li ered to the matching network s del e ed t the load An xampl of an L-sect o matching netw rk i llu t ated Mat h ng netw k f th type ar u ed in rad o-frequency ci cuits The val ie f in d ictan e a d cap a itance are cho en t ati fy the requ reme t f the maxim m p wer tr n fer th orem Th power d ipated in the matchi g net work is a mall f a ti n of that deli ered to the l ad b cau the elements u ed r cl se approxi mat ons of ideal c mp n nts



L-sect mped e-r h g tw k

Transformers The impedance mea red at the t rminals f one wi di g f an iron-c re tr ns form r i appr xim tely the alue f the imped nce c nne ted acro the ther term nals m lti pl d by th q ar f the t rn r t Th i if th lo d and ge e t r impeda c are n tan es th turn rati an be ch n to m tch th l ad resi t an e to the ge t r e tan e f r ma m m pow r tr nsf r If the ge erat r and l d mped ance cont i r acta es the tra sf rmer cann t b u ed fo m tch ng b cau it ann t hange the l ad mpeda ce to the conjug te f the ge rat r mpeda ce (the L- ect on mat h g etwo k can) The turns rat o can b ho en h wev t d l the ma mum p w r u der the nd ti s this ma i mum be ng less th th theo tical maxim m

Ir n ed tra sf rme a e d for imp danc match ng i th ud and i per frequency ra ge Th power d pated i the c re incr a es with fr qu y becau of hy te esi Abo th frequency ng t whi h ir n ed t n f rmers can be u ed the ir-core t n forme or tr form er with powder d i n sl gs a be ed eff c tiv ly H we r in these a s the turns-rat o-squared mpeda e-tran form ng p operty s no l ng r tru S n e the tr nsf rmer is u ually r rt of a t ed c rc t the fa t s i fluen e th de gn f th transforme

The impedan e t an f m g prop rty of an ir n ed t an f rme not lw y u ed t gi maxi m m pow r tr n fe For xample in the des gn f powe mpl fi r stages n aud o amplifiers the mpedance prese ted to th t be ff ts d stort n A tudy of g n circuit can oft n sh w that at a g v outp t p w level u ll th m x mi m ex pe t d th s lu f th l ad resi tance wh h w ll m m ze h rmo i c mpo ent in th ha m n d t rtion s ch s the eco d or th rd ha mon c Th tr sf rm t rn rat o i l ted to p t thi es ta t th i b S TRANS-FORMER

Cathode follower In le tro u try g nal s r f l rg nt nal imp d n m t fit n b c ted t l w mped n l d If th r e we o ted d ectly to th l d atten i o of

the signal would result. To reduce this attenuation a cathode follower is connected between the source and the load. The input impedance of the cathode follower is high, more nearly matching the large source impedance, and the output impedance is low, more nearly matching the low load impedance. In the usual case the cathode follower appears as almost no load upon the signal source. If the object were the delivery of maximum power to the load, it might be possible to design the cathode follower to have an output resistance equal to the load resistance, assuming that the load is a resistance. (Special audio amplifiers have been designed to use cathode followers rather than a transformer to connect the loudspeaker to the power amplifier. A number of cathode followers connected in parallel present an equivalent output resistance equal to the load resistance.) In many cases maximum power transfer is not the goal; the cathode follower is introduced primarily to reduce to a minimum the attenuation of the signal. See VOLTAGE AMPLIFIER. [H F K]

Bibliography: E. W. Kimbark, *Electrical Transmission of Power and Signals*, 1949.

Impedance measurements, high frequency

The electrical measurement of the complex ratio of voltage to current in a given circuit at frequencies from several hundred kilocycles (kc) to 100,000 megacycles (Mc). This frequency range includes the medium frequency band and higher frequency bands. See ELECTRICAL MEASUREMENTS.

At lower frequencies impedances may be accurately measured by standard techniques for measuring resistance, capacitance, and inductance. Standard resistors, capacitors, and inductors are often used as comparisons for unknown impedances at lower frequencies; these are very accurate standards. See CAPACITANCE MEASUREMENT; INDUCTANCE MEASUREMENT; RESISTANCE MEASUREMENT.

At higher frequencies the slight imperfections in impedance standards become objectionable, and unwanted impedances occur in circuit connections. Distributed parameter impedance standards consisting of coaxial transmission lines are useful at frequencies at which the distinction between desired and residual parameters becomes hazy. At the highest frequencies, where mechanical dimensions become comparable with the wavelength, resonant cavities and wave guides are used because they incorporate simple boundary conditions for field calculation. Connection errors are avoided whenever possible by substitution measurements in which undesired impedances are cancelled out. Two general methods are employed: resonance and null indication.

RESONANCE METHODS

Resonance is a typical phenomenon at radio frequencies. It is readily observed and reproduced and defines a circuit condition for which the interrelationship among the component impedances is known. It is therefore an excellent indicator for measurement purposes. Either series resonant or parallel resonant circuits can be used. Series-resonant circuits are best suited for measuring low impedances and conversely parallel resonant circuits for low admittances. Both methods determine the quadrature or reactive component of impedance from the change in resonant capacitance when the unknown impedance is inserted into the circuit. They differ in the method of measurement of the real or resistive component of impedance. See RESONANCE (ALTERNATING CURRENT CIRCUITS).

Series resonance methods. Two methods of obtaining the necessary data to permit solving for the unknown impedance are employed.

Resistance variation method. A short circuiting link is first connected across the terminals shown in Fig. 1 and the circuit is tuned to resonance as indicated by a maximum current reading. This current I_1 is then given by

$$I_1 = \frac{E}{R} \tag{1}$$

where E is the source voltage and R the total circuit resistance.

The short circuiting line is then replaced by the unknown impedance Z and resonance reestablished. The new current I_2 is

$$I_2 = \frac{E}{R + R} \tag{2}$$

where R is the resistive component of the unknown impedance Z.

Finally the unknown impedance is replaced by a known standard resistance R and resonance is reestablished. The current I is

$$I_3 = \frac{E}{R + R} \tag{3}$$

Combining Eqs. (1), (2), and (3), one obtains for the unknown resistance

$$R = R\,\frac{I_2(I_1 - I_3)}{I_3(I_1 - I_2)} \tag{4}$$

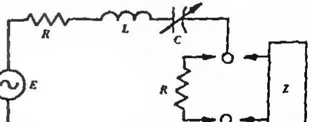


Fig. 1. Series-resonance circuit for resistance-variation and reactance-variation measurements.

The unknown react nce X is g en by

$$X = \frac{1}{\omega}\left(\frac{1}{C} - \frac{1}{C}\right) \quad (5)$$

wh C_1 and C e the tt ngs of the v riable ap itor f r n n w th th hort-circ iting l nk nd th u kn wn mped nc ir u t re pec t ly a d ω i th e gul r freq ncy

R a t c ar tion m th d Th method diffe s from th ■ ■ ariat method only n the mea m t f th unkn wn re t e c mp ne t Th c r u t e sta c d duced fr m the apaci t e cha ■ ecess v t detu the c r t by a k n m u t

Th u t s fi t tu ed to res nance and th u t I oted the th c r u t i detu ed a d th capa t n e l e C a d C for whi h the c r e t bec m s 0 07I are det rm ned At th et ti g n n ach de f r so n the c t re ta c q l th r u t e t c R a d it can be h wn that

$$R = \frac{1}{2\omega}\left(\frac{1}{C'} - \frac{1}{C}\right) \quad (6)$$

A m a eme t w th th h t r u ti g l nk in pl e y ld s t c R wh h is equ l t the t t l c t r tan e R A d me em nt w th the hort-c t ng l nk epl ed by the un k wn impedance Z y ld a res tance R_2 wh h eq l t $R + R$ Th sub t t t o m a u em nt the ■

$$R = R_1 - R \quad (7)$$

$$X = \frac{1}{\omega}\left(\frac{1}{C_2} - \frac{1}{C}\right) \quad (8)$$

Parallel resonance methods Th pa ll l re a m th d r d l f the eries n n e m thod The sam g l t h que e ed c pt th t e a c defi ed term f maxi m m ll g d th e it l s s a e m a ed by th pe r t o d t e G in tead f th h rt r t e ta R (F 2)

C du t n t n meth d Th s method th d l f th es t n e a t t n meth d M as me t th th t rm al p u ted with th k dm ttan e Y n t d d th n with th k wn dm tt n e pl ed by a kn wn nd t n e t nd d G g

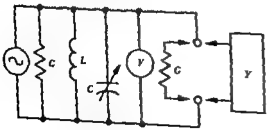


Fig 2 P ll l r so c cu t f d ct e-vari- tio d usc pt e- ato m m ts

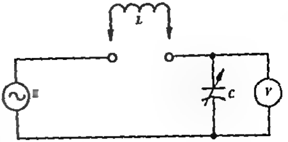


Fig 3 Se se s c tued f r so a t ■ m thod of m i g Q

$$G = G\,\frac{I_1(I_1 - I_2)}{I_2(I_1 - I_3)} \quad (9)$$

$$B = \omega(C_1 - C_2) \quad (10)$$

where th sub cr pts refer t the three mea ure- m nt re p ti ly

Suscept e t n t o method This method i the dual of th e cta ce- ■ ti n method At the ap c ta c tt ng C and C' for wh ch the c rcuit u cepta ce q als the ci cuit conductance G th ltage becomes 0 07I and

$$G = \frac{\omega}{\cdot}(C' - C') \quad (11)$$

The am q e c of m ■ ement a in the re ct ce-a ati n method then yields

$$G = G - G_1 \quad (12)$$

$$B = \omega(C_1 - C) \quad (13)$$

Th eso a ce methods ■ e accurate r ults w th fai ly mple equipment but a e not read ly made di ect read ng and a therefore not u ed ■ the bas for c mm rcial i tr me t

Resonant rise method A c rc t that has bee wid ly u d c mmercially to mea re the stor ge fa t Q of c ls i sh wn in Fig 3 Comme ially th in trument k ow a a Q mete (*see* Q METER) The e na t c rre t I in th ser es re o- n nt i cuit a befor ■ g ■ by

$$I = \frac{E}{R}$$

nd th voltage V acr the t ning capac t r C b

$$V = IX_C = IX_L \quad (14)$$

whe e R i th t t l c c it r stance nd X_C and X_L r the e cta c s of the apacito C a d in d cto L espe t ely Th ltage r t V/E the ef

$$\frac{V}{E} = \frac{X_L}{R} \quad (15)$$

If th re ta nd du tan e of th r st of the t m d gl g bly small c mpared w th th e ta and induct n e f the c l L the ltag V will be d r ctly p op t on l t the st r g f ctor

the signal would result To reduce this attenuation a cathode follower is connected between the source and the load The input impedance of the cathode follower is high more nearly matching the large source impedance and the output impedance is low more nearly matching the low load impedance In the usual case the cathode follower appears as almost no load upon the signal source If the object were the delivery of maximum power to the load it might be possible to design the cathode follower to have an output resistance equal to the load resistance assuming that the load is a resistance (Special audio amplifiers have been designed to use cathode followers rather than a transformer to connect the loudspeaker to the power amplifier A number of cathode followers connected in parallel present an equivalent output resistance equal to the load resistance) In many cases maximum power transfer is not the goal the cathode follower is introduced primarily to reduce to a minimum the attenuation of the signal *See* VOLTAGE AMPLIFIER [H F K]

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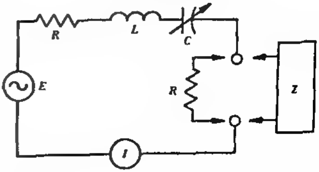


Fig 1 Series-resonance circuit for resistance-variation and reactance-variation measurements

The u kn wn actan e X s g en by

$$X = \frac{1}{\omega}\left(\frac{1}{C_2} - \frac{1}{C}\right) \qquad (5)$$

here C nd C are th s ttings f the variable c pa it r for e n nc with the sh rt cuiting l k d th unkn wn imped nce in c uit re pec t ly a d ω s th a gula f eq ncy

R a t ce a t tı n m thod Th m thod d ffers fr m th ta c a t tı n m th d nly the m a u em nt of th unkn wn e tı c mpone t The r u t res ta ce deduced f om the capa ı t n chang ne sary to d tu e the circu t by a kno n m u t

Th ı cu t s fi t tuned to res a e and the rr t *I* n ted the the ct c t ı detuned nd the cap c ta c l e C and C for wh ch the cur t b c me 0 07*I* ar d te m ned At th et ting o e on cf d f re n e the circuit eact n equal the ı c t res t n *R* and it c n b hown th t

$$R = \frac{1}{2\omega}\left(\frac{1}{C'} - \frac{1}{C}\right) \qquad (6)$$

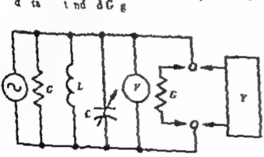
A me ur ment w th the hort cu ting l nk ı pl y eld re ta *R* whı h s qu l to the t tal c t r ı ta e *R* A e nd mea urem nt w th the h rt-c ting l k r pl d by th u k wn mpeda c *Z* y eld a res t nc *R* which ı equal t $R+R$ Th s b t t ı o m a reme t the g

$$R = R_2 - R \qquad (7)$$

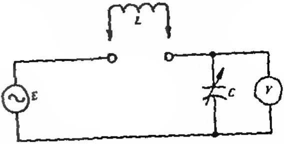
$$X = \frac{1}{\omega}\left(\frac{1}{C} - \frac{1}{C}\right) \qquad (8)$$

Parallel resonance methods The pa allel re m thod a d ls of the s r es eso nce meth d Th m g n al tech q es a e ed pt that a s defin d term f maxi m m ltage d th c r u t lo are mea ed by th pe c u t d tanc *G* n t ad f the sh rt t t *R* (F g 2)

C nd t ariat meth d Th s m thod th d l f the es ta c a t n m thod M a m nt w th the t rm nal pe ı ted w th the u kn wn dm tt nce *Y* o ected d th n th th nk ow dm tt e r pl d by a kn wn d ta t nd d G g



Fg 2 P ll l-r ıfo o d ct e- l- no d sc pt e- l l m m t



Fg 3 5 o n e c cut s d fo sona t n e m th d of m g *Q*

$$G = G\,\frac{V_3(V_1 - V_2)}{V_2(V_1 - V_3)} \qquad (9)$$

$$B = \omega(C_1 - C_3) \qquad (10)$$

wher the ub cript refer to the three mea ure ment re pecti ely

Susc pta ce t riation method This method ıs the d al of the reactance-variat on m thod At the apa it n e etting C and C' for which the c rcuit s cepta ce equals the *circ t c nductance G* the oltage bec mes 0 07*I* and

$$G = \frac{\omega}{2}(C' - C) \qquad (11)$$

The same q ence of m a urement a ın the re ct nce-v iatio method th n yields

$$G = G_2 - G_1 \qquad (12)$$

$$B = \omega(C_1 - C) \qquad (13)$$

The so anc method g accu ate results with fai ly s mple equ pm nt but a not read ly made di ect reading a d are therefore not u ed as the basi f ommerci l instruments

Resonant rise method A c rcu t th t has been wid ly u ed ommerc ally t m a the torage f ct r *Q* f co ls shown Fig 3 Comm rcially the ı tr ment ı known a Q met r (se Q METER) The eso nt curre t *I* ı this series e o na t ci u t a b fo e t en by

$$I = \frac{E}{R}$$

nd th v ltage *V* acr s the tuning cap c t *C* by

$$V = IX_C = IX_L \qquad (14)$$

where *R* ıs th total ı c t re ı tance and X_C and X_L ar the actanc of the c pa itor *C* and in du tor *L* pe t ly The v ltag t o *V/E* s the f r

$$\frac{V}{E} = \frac{X_L}{R} \qquad (15)$$

If the tan e a d du t ce f the rest of the u t ar m de n gl gibly mall mp ed w th the re stance nd ı d tance of the c il *L* the v ltage *V* will be d *rectly* prop rt nal t the st g f cto

Q of the coil In the Q meter illustrated in Fig 4 the voltmeter cale is calibrated directly in Q and the value of the unknown inductance is determined from the calibrated capacitor setting by means of the relation

$$L = \frac{1}{\omega^2 C} \tag{16}$$

Knowing L the effective resistance of the induct ance is given by

$$R_L = \frac{\omega L}{Q} \tag{17}$$

Q of a tuned circuit or cavity Several methods of measuring Q are available

Resonance curve method If frequency is varied so that the current in a tuned circuit or cavity goes through resonance and the frequencies f and f for which the current is reduced to 0 707 of its maximum (half power points) are noted it can be shown that

$$Q_0 = \frac{\omega_0}{\omega - \omega} = \frac{f_0}{f - f} \tag{18}$$

where the subscript 0 refers to values at resonance For high Q cavities at microwave frequencies this measurement is usually performed by coupling the generator and detector to the magnetic field with mall pick up coils so oriented that direct pick up from one to the other is negligible If the couplings are too strong the resonance curve will be broad ened by losses coupled in from the generator and detector As they are weakened however this broadening will disappear and the observed curve will be that of the cavity alone

Decrement method The storage factor Q of a resonant device repre ents the ratio of the maxi mum energy stored in the electric or magnetic field during a cycle to the amount of energy dissipated in that cycle It can al o be measured therefore l y obser ing the decay in o cillation amplitude when the exciting signal is cut off The current in the tuned circuit then follows the law

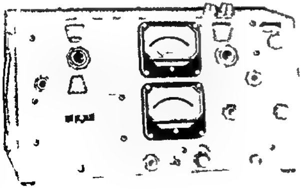


Fig 4 Boo ton Q mete used to m asu e d cto c a d Q o r th f eque cy ge f om 50 kc to 50 Mc (Boo to Rad o Co p)

$$I = I_0 \epsilon^{-(R/2L)t} = I_0 \epsilon^{-(\omega_0/Q_0)t} \tag{19}$$

where t is time I_0 the initial re onant current and the other symbol carry their previous connotati n The cavity Q_0 is then related to the time interval Δt during which the current decays by a factor of $\epsilon = 2\ 71828$ by

$$Q_0 = \frac{\omega_0 \Delta t}{2} \tag{20}$$

See TIME CONSTANT

This mea urement is carried out with a pul e modulated generator a detector having a large bandwidth compared with that of the cavity to l e measured and a cathode-ray oscillo cope The detected signal which measures the cavity current is applied to the vertical plates of the o cillo cope and the horizontal deflection is synchronized with the modulating pulse to produce a stationary pat tern This pattern may be scaled directly off the screen for rough measurements or in a more com plex set up the pattern may be compared with the discharge curve of an RC network excited by the modulating pulse

R_0/Q_0 of a resonant cavity At microwave fre quencies where a resonant cavity may be difficult to analyze as an equivalent LC re onant circuit it is often necessary to measure the quantity

$$\frac{R_0}{Q_0} = \sqrt{\frac{L}{C}} = \omega_0 L = \frac{1}{\omega_0 C} \tag{21}$$

to obtain in conjunction with a measurement of Q_0 a value for R the effective hunt resi tance of the cavity This is most often done by the perturba tion method

If C can be varied in an LC circuit it can l e shown that

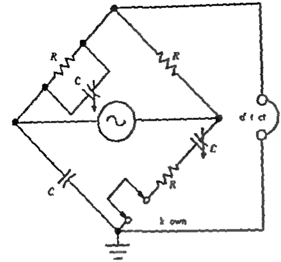
$$\frac{R_0}{Q_0} = -\frac{2}{\omega_0^2}\frac{d\omega}{dC} \tag{22}$$

Analysis of the field in a microwave ca ity when a perturl ing object is introduced can l y analogy be used to relate the re ultant change in frequency to R_0/Q

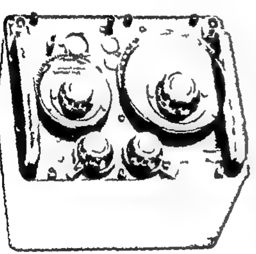
NULL METHODS

A phenomen n at lea t equal in importance t re onance a an indicator of pre ril ed ir uit on dition i l alance Tl e preci i n with whi h the difference l etween two alternating v ltage an l e reduced to zero can ea ily reach a few part in a milli n Null m th l are alm t uni ally u l for the mo t pre i mea urement

Radio frequency bridges At radi fr q i nci the problems ari ing fr m r i l i l param ter make u f variable air pacit r a ımp lan tandard in sul titution metl l de ir l l f r n ıll device a f r re nant ir uit Sp ial ir c it that ar parti ilarly w ll a lapt l f tl fre juen ie l ave tl er f re l n l l p l The widely u d comm rcial in trum nt ar li l



Fg 5 C t hem tc f G l R d r do-f e- q cy b dg



Fg 6 G l R d do-f eq cy b dg (G l R d C)

C al Radio rf bridge The balance c nditi ns for th s br dge l wn in Fig 5 and 6 yi ld tl unknown re i t ve comp nent R and tl e unkn wn reactive c mponent X of impedance in term of th k wn bridge components R_B C C_A and C_P

$$R = \frac{R_B}{C_N}(C_{A2} - C_{A1}) \tag{23}$$

$$X = \frac{1}{\omega}\left(\frac{1}{C_{P2}} - \frac{1}{C_{P1}}\right) \tag{24}$$

As ndicated both the re i ti e and react e com p nent are mea red in term f capac tance d ff ren es the b cript 1 and 2 refer re p c t ely to l la n with the termin ls fir t short ircuited and econd con ct d t the unknown impedan e The dial f the capacitor C i cali brated in ohm ndep nde t of freq iency and tl e d al of the apacit r C_P in hm at a freq ency of 1 M At other frequenci the reading f thi r ctanc dial mu t l e d v ded l y th frequency in meg c les The in t ument co er the frequency ra g fr m 400 kc to 60 Mc th r ver i n extend th e lim t to 50 kc and 120 Mc.

Wayn Ke r rf bridge Tl is l r dge u a ce ter tapped t an f rmer with a l gl deg ee f coupl ng betwe n w nd ng to dev l p qual and oppo te voltag s in the tandard and nkn wn arm (F g 7) A m lar tran fo mer w th one wind ng re r ed upl s the utput t the detector A shown n Fig 7 t p a u ed to mod fy the effe t ene s of the capacitanc and ondu t nc tandard C and G re pecti ely In term f the numb r f t rn n betwe the center tap and th unkn wn adm tt n e (n) th cond ct nce standa d (n_2) nd th ap cita c st ndard (n) the balance nd t n are

$$G = \frac{n_2}{n}G \tag{25}$$

$$B = \frac{3}{n}\omega C \tag{26}$$

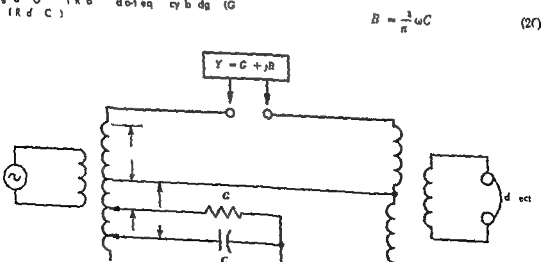


Fig 7 S mpl f d d ct t o-arm b dg

Combinations of switched fixed value standards and continuously adjustable standards yield scales that are calibrated directly in conductance and capacitance independent of frequency. Similar taps on the unknown side of the center tap are used to switch admittance ranges. The instrument covers the frequency range from 15 kc to 5 Mc; other versions extend the range from 15 kc to 250 Mc.

Bridges of this kind are particularly well adapted to the measurement of the direct component of balanced and other three terminal admittances because the shunt components can be thrown across the low impedance transformer windings by grounding of the center tap and eliminated from the measurement. They can also be adapted to the measurement of the transfer impedance of four terminal devices.

Boonton RX meter. This bridge uses the same configuration of bridge arms as the General Radio bridge but measures the unknown as an admittance in the A arm rather than an impedance in the P arm. For this inversion the balance equations become

$$G = \frac{C_N}{R_B}\left(\frac{1}{C_{P2}} - \frac{1}{C_{P1}}\right) \qquad (27)$$

$$B = \omega(C_{A1} - C_{A2}) \qquad (28)$$

The RX meter differs from conventional bridges in that the bridge arms are excited by out-of-phase voltages from a transformer. At balance the junction point voltages are equal in magnitude but opposite in phase. The null voltage is therefore obtained between the center point of a capacitive voltage divider and ground as shown in Fig. 8.

Microwave null devices. At frequencies so high that the distributed nature of parameters must be

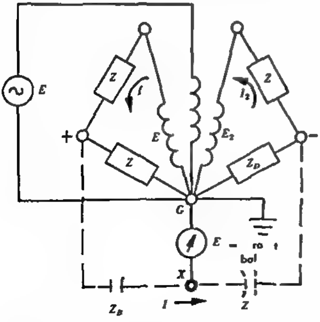


Fig. 8. Circuit schematic of Boonton RX meter. Special three-winding transformer couples out-of-phase voltages from the generator to the two halves of the bridge and the two capacitors Z_B and Z provide a center tap to feed the detector.

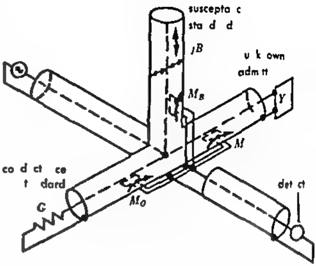


Fig. 9. Functional diagram of General Radio admittance meter. The three loops M_B, M_G and M sample the magnetic fields in the susceptance, conductance and unknown admittance arms respectively and combine the outputs in the detector arm.

taken into account the principle of null comparison can still be used to effect precise adjustment. There are three widely used commercial instruments for this frequency range.

General Radio admittance meter. This instrument, shown in Figs. 9 and 10, samples the magnetic field arising from the current in each of three coaxial transmission lines through adjustable loops (M_B, M_G and M) coupled to their center conductors at their junction point in the T configuration shown in the figure. All the lines are fed at this point from a common voltage and thus the currents bear the same relationship to each other as the respective admittances seen looking into each of the lines. One of the lines is terminated in its characteristic impedance Z_0 to present a standard conductance G equal to $1/Z$; one is terminated in an eighth wavelength transmission line to present a standard susceptance B equal to $1/jZ_0$ and the third is terminated in the unknown admittance Y equal to $G + jB$. The coupling loops can be rotated by means of shafts carrying dials, the first two being calibrated in conductance and susceptance respectively and the third in admittance range. The loop that couples to the susceptance line is adjustable over a 180° range to indicate either positive or negative susceptance. If the eighth wavelength line is set to the proper length for the operating frequency so that both conductance and susceptance scales are direct reading independent of frequency. If the unknown is connected to the instrument by a ¼ wave line the readings of these scales become directly proportional to impedance. The instrument is direct reading for the frequency range from 40 to 1000 M

Transfer function and immittance bridge. A modification of the admittance meter ... mpar ... the output current of a four terminal device with admittance standards in a T configuration similar to that described above ... by making po... ... m a

u em nt of transfer adm ttanc by a null method Thro gh the u e of ½ wa e and ¼-wa t an m s-on l es in th inp t nd tput circu t it i po bl t mea u e the r ti f tp t current to input olt ge o tp t v lt ge t nput ur e t out p t t i put olta a d output to put curr nt A nt r ha geabl head c n rts the in t ume t t a adm tta e m ter making p ble mea ure-me t of t o-termin l dm ttan e ard imp d nc Th nst ument o s the f equency r nge from 25 to 1000 Mc

H ulett Pack d hf br dge In th i strument hown i Figs 11 a d 12 a apacit e p obe m as-ures th le tric fi ld nd a nd cti e p be th m g t c field of oa i l l ne at th po nt t which it e ect to the nknown imped nce A g ged control adju ts the r lati e d gree of cou pl g of the tw probes and is calibrated to in l cat mped nce magnitude d rectly when the two i duced voltag s are equal The probe i tputs are appl ed to the two end f a lott d l ne wh e xt lies in a circl about a point f om which a ear h p ob swing Th ign of the mutual ind ictanc of the inductive pr be i o cl o e that f r equal nduced olt ges the capacit e and ind cti e ig nal c ncel at the center of the l tted line when th unk wn impedan e is purely resi tive Th d placement of th ea ch pr b fr m thi center positi n f r balanc s then proport nal t the pha e angle f any arb trary unknown impedance and a d al ttached t the shaft on which it i mounted s calibr ted in deg ees for a freq iency f 100 Mc At f equ ncies other than 100 Mc the read ng mu t b multiplied by the f equency in m gacy les nd d ded l y 100

Fig 10 G l R d dm tt m t w h bl p it ect d o pl e d d (G l R d Co)

Standing wave detector Sta d ng w e d tec tors ar dev c ed t mi r wa e freq i nc to mea re impedan es in terms of *electromagn ti* field d tr l tion in gu ded wave y tem

It is des r bl t make uch me urement with de ces of mple g met cal configurat n that th r perfo ma ce can be r ad ly analy ed n term f field theo y At the lower microwa fr q i nc es wher t an ve se dimen ons are m ll compared t th wa length the p rf rmance of co xial lines is ea y t compute a d thes de ices can b c nduc t ly on ected to irc its chara terized by two-te mi al on ect ons At the high r m cr wa e frequen ie wh re all d mensi ns are omparable with the w l ngth and th c nc pt f l mped r e e d t ibuted p m ters is no l nger re d l u abl wa e g i d ha e impl bound ry ndi t that fac litate o mput tio and v u l zat o of field d tr but n Th y b c ipled t th r wa e gu d s o to c tie thr ugh el ctric or mag net field rath r than with n d ri e nnect n *See* T A S I SSION LI ES WAVE GUIDE.

Impedance n be meas d with th e t n m s-n l ne by an ly f the b havio of electr c fi lds p opag t ng alo g the r xes In an deal z d o i l l ne o wa e gu de w th lo sle s, u ity d ele t c c sta t in ul ti n and perf ctly c n duct g w ll a plane wa e will p op gate along th ax s at th peed of l ght w thout alter t n long a th o s-ect n l d mens ns r ma n un fo m Th relati n h p b tween the ele tr c nd m g t fields w ll ma n sta t and b ca e th are respect ly p op rt n l t v ltag and curre t th at of the e fi ld w ll defin ha t t c imped n f the l

Whe th w r a h th nd f th tr mis s o l n a po t n det rmi ed by the mpedanc d s t nu ty t th t p nt i r fl t d backward t wa d th s e Th n dent nd fle ted wa e then add togeth t form a t tio ry nt rl c patt r ta d g n that has m xi a nd minima oc urr ng altern t ly at i t rvals f ¼ w v l ngth (s STA I C WAVE) Th m x ma ccur t th poi t i wh h the wa s r nf each th a d m a u the sum of th two m l

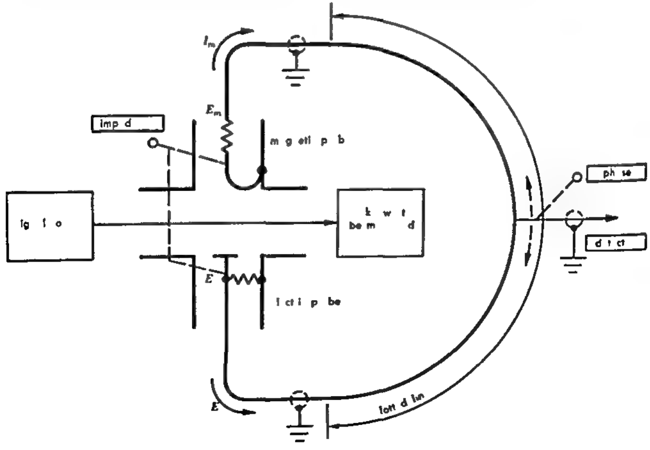
tudes the minima conversely measure their difference The ratio of maximum to minimum voltage *is called the voltage standing wave ratio* (VSWR)

The amount of reflection depends upon the relation between the impedance in which the line is terminated and the characteristic impedance of the line If the impedance is resi tive and equal to the characteri tic impedance the current will flow into it just as it would into a further exten ion of the line itself and there is no reflection if the transmission line is short circuited the reflected voltage will be equal in magnitude but of reversed polarity to the incident wave because the net voltage must be zero at the termination if the transmission line is open circuited the reflected voltage will again be equal in magnitude but of like polarity to the incident wave o that the voltage doubles at the termination When the terminating impedance equals the characteristic impedance the VSWR is unity and the line is aid to be matched When the line is short circuited or open circuited the VSWR would be infinite if the line were lo sless The distance from the termination to the fir t minimum is respectively zero and ¼ wave length for the e terminations

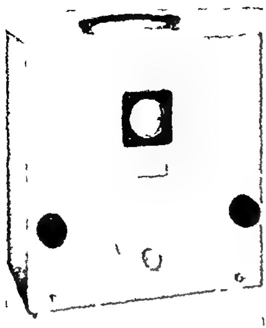
It can be shown that these two quantities the VSWR and the di tance to the first minimum *uniquely define the terminating impedance* They are ea y to determine experimentally but the mathematical conver ion to the conventional impedance components i somewhat involved Graphical methods of interpretation have therefore been developed and one known as the Smith chart i *in wide u e both for determining impedance from* standing wave measurement and for analyzing the effects of finite lengths of connecting line

Slotted line A commercial slotted line for measuring impedance at the lower microwave frequencies is shown in Fig 13 It compri es a cylindrical coaxial line having a lot in the outer conductor into which a mall capacitive probe extend to sample the electric field As the probe lides al ng the line its po ition can be mea ured to find the distance from the termination to the fir t voltage minimum and the maximum and minimum voltages determined to find the VSWR This line is uitable for measurements from about 300 to 5000 Mc

Slotted section A commercial lotted ection for measuring impedances at the higher microwave frequencies is hown in Fig 14 It function is similar to that of the coaxial lotted line but it differs in certain practical re pect Coaxial lines cover the frequency range from dc to the frequencies at which the higher order modes of propagation u ed in wave guides occur Wave guide on the other hand are re tricted to the relatively narrower frequency ranges over which a ingle elected dominant mode is u eful Replaceable slotted sections are therefore provided o that a wide frequency range can be covered with a ingle carriage mechani m The e various sections cover the frequency range from 2 600 Mc to 40 000 Mc with two models of carriage



F g 14 F nct onal d agram of H wlett Pack rd hf b dge



Fg 12 H wl tt P d hf b dge (H wlett-P ka d C)

Microwave reflectometer A reflect meter p-arates the i cident f refl cted wa es in a trans-m ion l ne and me ur their ind id ial ampli t de The rati of the e ampl tudes i equal to the m g n de of the reflecti n coeff i nt $|\Gamma|$ f the t rminating impedanc The VSWR an be determined fr m

$$\mathrm{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|} \qquad (29)$$

To m a ure the term nat ng imped nce t elf an addit onal me ur ment f pha e hift at the p i t of eflecti n neces ary The reflecti n coeff c ent an th n be rep e ented s a ect i l quantity $\Gamma/\underline{\theta}$ r lated to the term nat ng impe lan e Z_L a d the char cte i t c imped n e Z_0 of the tran mis-i n l ne by

$$\Gamma = \Gamma/\underline{\theta} = \frac{Z_L - Z}{Z_L + Z} \qquad (30)$$

f om wh ch
$$Z_L = \frac{\Gamma + 1}{\Gamma - 1} Z_0 \qquad (31)$$

A ba i ompo ent of th reflect m ter the d ection l o pler wh h pe f rm th actual

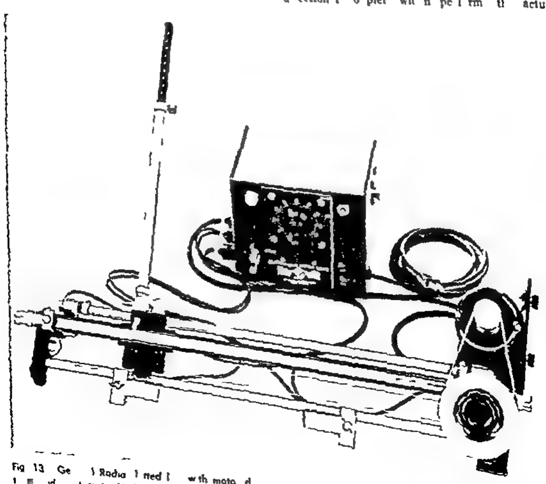


Fig 13 Ge l Radio l ned l w th moto d l d t m tic V WR d pl y (G l R d C)

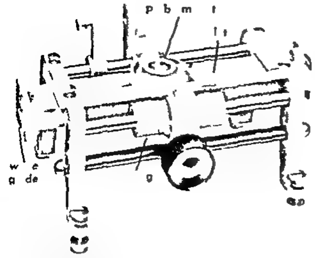


Fig 14 Hewlett Packard slotted section for microwave measurements. Different wave-guide elements can be inserted in the carriage for different frequency ranges between 3 950 and 18 000 Mc (Hewlett Packard Co)

eparation of the two waves Two of these coupled to the transmission line in opposite directions yield indeI endent measurements of the two waves from which their amplitude ratio can be computed A convenient arrangement uses a ratio meter to display the magnitude of reflection coefficient directly The angle θ of the reflection coefficient can be measured with an auxiliary slotted line to determine the distance from the termination to the first voltage minimum with an auxiliary capacitance probe to indicate the vector sum of the incident and reflected waves at a known point on the line or by *comparing the phases of the outputs of the directional couplers themselves*

A commercial instrument that performs a function *similar to the reflectometer s is shown in* Figs 15 and 16

A rotating loop at a T junction couples to the magnetic fields of the three component arms which

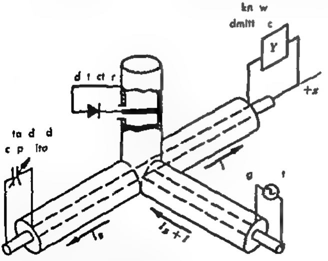


Fig 15 Schematic rep es tat o of PRD st d g wa e ind cator The detector loop shown can be ot t d ■ ary its coupl g w th the mag t c Felds g erated by the c re ts in th T ju ct on

are connected respectively ■ a su ceptance tand ard the unknown admittance Y and a ource of *rf power As the loop is rotated the induced voltage* varies between a value proportional to the um of the currents in the standard and unknown arm $I_S + I$ *when it is aligned with the generator arm* and a value proportional to the difference of the e currents $I_S - I$ when it is aligned with the other two arms For a setting of the susceptance standard that makes the arm admittance equal to $1/jZ_0$, the ratio of the minimum and maximum output which occur at ettings spaced by 90 equals the VSWR It can also be hown that the angle of the loop at which the minimum occurs when measured from a 45 position between the generator and unknown

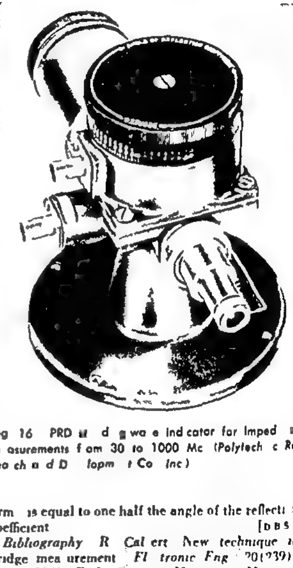


Fig 16 PRD st d g wa e ind cator for Imped ■ m asurements f om 30 to 1000 Mc (Polytech c Re sea ch a d D lopm t Co Inc)

arm is equal to one half the angle of the reflecti n coefficient [D B S]

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r sonan e methods, *Pro IRE* 6(1?) 1466–1437 1938 P H Smith T an mi sion li e calculator *El ctro ics* 1 (1) 29–31 1939

Impetigo

A c ntagi us ki d comm nly s en n ch l d but al f und in ad lt It au ed by either tr ptoc al or t phyloc cal infe t ns o by both Th d as s aut in culable th t i it can be q kly p ead fr m an rig nal t to any part f the body No immu ty i c nferr d by exp ure S e STAPHYLOCOCCUS STREPTOCOCCUS

The les s r sup rficial th n walled bl ter wh ch r ay de el p i t pu t les These b me e ed w th a thi k adhe e t r t and the ur ro d ng k s red d tchy The face calp and extr mit e m t (ten i l ed b t l ns may ppe r ywhe e in l din the m u s m mbra es f th eye and mouth

P d p g fa to n l d poor hyg ene in adequ t di t and wd d livi g c nd ti s In ries mpet g m y qu kly l c me epid m c s nc th newborn a espe i lly u e pt bl

Imp t g f equ ntly f ll ws th r di o ders, p t l rly th e wh h p odu ses re it h g nd sub q e t r t h g u h a s able nd ped n lost

Only r r ly is th d a e e s i s fa as mor t l ty i c n er d except i nfant T eatme t employ fr q nt le n ing nd lo al ant nfec t e g ts u h s the n w r nt l oti s S e ANTIBIOTIC.

[E C S T]

Impsonite

A bla k n t lly o curr ng a bon eo mat ri l h v ng pec fic gra ty 1 10–1 25 nd fix d a bo 0–8 % Imp on t i inf bl a d s lubl in bo d lfid A e i f imp it 10 ft wid oc cu La Fl re County Oklahom and the e a the d po it n A k n s Nevad M h g n P A ge t na Br l nd Au t al a The Peru i n mp ite may be d ed from g ab mite by w ath g The o igi of mp o te i ot well n d r tood but t pp r to b d ed fr m a fl d b t m that p lym ed ft t filled the v n n h h t s f u d

Imps tes e k wn t nia nu ually high ges f n d m S ALBERTITE ELATERITE WUR ITE e l A H L A SPH L

[I A B]

Impulse (mechanics)

Th t gr l of f n i t rv l of t me F r f F th mp l J r th nterv l f m t to t b w it

$$J = \int_{t_0} F\,dt$$

Th impul thu r p e nt th p du t f the time i rv l nd th a ag f a t ng d r ng the i l al Impulse ect q t ty w th th un t of m m t m

The m me tum mpul e relat n tate that the change n momentum o er a gi en time interval equals the impul e of the resultant force acting d ir ing that interval Th s relation can b pro ed l y i t grati n f Newt n s econd law ver the time interval fr m t to t Let P repres nt the m mentum at time t with P and P_1 being the alu f P at t mes t_0 and t respecti ely Th en

$$J = \int_{t_0} F\,dt = \int_{t_0} (dP/dt)\,dt$$
$$= \int_{P}^{P} dI = P_1 - P_0$$

If as s ordinar ly tru the ma m is c n t nt the m mentum change can be expres ed i terms of the velocitie v_1 a d v_0 at times t_1 and t_0 re pecti ely gi ing

$$J = m(v - v)$$

The co cept of mpul is ordina ly m t u ef l wl en the force are la ge but *act only for a hort* p r od I m t of the e ca es one needs i kn w nly th mom tum change wl ch i det m ned by the impul e Th el ti n b twe n *moment* m a d imp l e tl u has the ad ant of el m nating the need f r detailed k wledge of l ow tl e fo ces wh ch can be very c mpli ated cha ge with t m For es wh h occur dur ng c ll i are f th t p S e C LLISION

A furth r mpl fic tio of th s type of sy tem i obta ned if th time interv l i short e ough for the sy tem to be c de ed e ent ally tat nary d r ng the t me of act on of the f ce o th t the mo m nt m ha ge oc ur almo t i ta ta eou ly Fx ept for the cl anged m mentum the moti n of the y t m i tre ted as t w uld h been if no im p l e had o c r ed The effect f th impi l can th i be e n d r d t pr ide a t of inst l c n d ti for the moti In b llist c galvanom te fo e mpl the e is n el ct rent fo o ly a hort t me during which the gal an mete c il r ginally at rest i g n n imp l e by the f e s oc at d w th th c e t The nly eff ct of th ur e t n th l i r motio f the il wh h can be o ide ed st t on ry d r ng the t me th re s rrent i t p o de n in ti l elo ity for the b equent m ti n S G LVANOMETER IMPACT (IMPULSIVE FORCE) MO ENTU

[P W S]

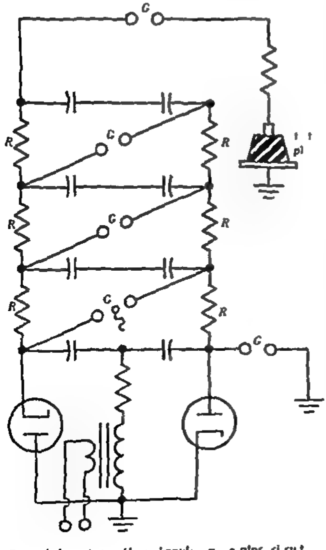
Bibliography J W Campbell *A I t oductio t Mecha cs* d 194

Impulse generator

An l tr al pp ratus wh ch p d ce ery short rges f high lt g r *h gh current* pow r *H gh imp l e volt* ed to t t the stre gth of i lators a d of p w r equ pment ag st l ghtn ng a d witch ng s rge H gh u r t im pul a e prod ic d by th d sch rge of nden rs c ected n pa all l S h curr nt u g may b sed to m gn t p rman nt magnets or to p o d e the r s ng r agnet c fi ld ircula p rt le c l r t s (se PARTICLE A CELERATO)

High voltage impulse generators commonly employ the principle originally suggested by E Marx of charging condensers in parallel and di charging them in erie The figure shows a four tage Marx circuit in which the conden ers C are first charged in parallel through charging resi tors R then connected in eries and di charged through the te t piece by the simultaneous sparkover of park gaps G The di charge is precipitated by placing a sufficient voltage on the middle elec trode of the three electrode gap between the fir t and second condenser banks

Although 1–2 × 10 volts (peak) is most com mon over 7 5 × 10 volts to ground have been ob tained The waveform shows a rapid ri e followed by a less rapid decline to zero expre ed by $v \propto (e^{-mt} - e^{-nt})$ where v is the instantaneous volt age t seconds after onset of the di charge and m and n are the exponential decay constants of the circuit Typical indu trial laboratory waveforms are the 0 5 5 the 1–10 and the 1 5–40 in which the fir t numl er is the time in micro econds to the peak of the voltage wave and the econd is the time to one half voltage on the tail of the wave These di charges imulate the transient voltages induced in



Typ cal fou -stage Ma x impuls g e ator ci cu t

electrical conductors by natural lightning [J C TL]

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Impulse turbine

A prime mover in which fluid under pre ure enters a nozzle where its pre sure (potential energy) is converted to velocity (kinetic energy) the fluid then impinges on blades of a rotor imparting it energy to the blades to produce rotation (see TURBINE) The fluid may be water steam or h t gas (see HYDRAULIC TURBINE STEAM TURBINE TURBINE PROPULSION) The action i continuou thus a de ignation such as pre urele s would be more descriptive although impulse is e tabli hed by long usage See PELTON WHEEL see also REACTION TURBINE [F H R]

IMViC test

A mnemonic for a group of four cultural te t u ed to differentiate genera of bacteria within the family Enterobacteriaceae The e te t are de cribed in the following paragraphs

Indole This is a putrefactive compound produced by some bacteria from tryptophan The bac teria are inoculated into a broth made with an en zymatic dige t of ca ein (see CASEIN) After a 2 hour incubation at 37 C a olution c mpo ed of *para* dimethylaminobenzaldehyde amyl alcohol and hydrochloric aci l i added A po itive reacti n is the appearance of a red color in the alcohol layer indicating the pre ence f ind le

Methyl red This i a te t f r the ability of cer tain bacteria to ferment carbohydrate and form acid The pH of a culture containing 0 5% gluco e is determined after 4 day at 37 C If the pH is be low 4 5 (the pH at which the indicat r methyl red turn red) the micr organi m i termed methyl red po iti e

Vosges Proskauer Thi i a qualitati e te t for the formation of acetyl methyl arl in l fr m glu co e A large ino ulum of the rgani m under study i made into a tube of gluc e br th incu bated f r hour at 30 C S luti n f α naphthol pota ium hydroxide an l reatine are a l led t the culture A p itive rea ti n i in li ated by a pink t r e l r

Citrate Th i a te t f r the ability f an r gani m to utilize odium citrat a a le source f c rbon A me lium i prepar l with p t ium dihydrogen pho phate (KH_2PO_4) magne i m ul fate ($MgSO_4$) sodium ammonium pho phate ($NaNH_4HPO_4$) and sodium cit ate ($Na_3C_6H_5O_7$) in li till d wat r A small ino ulum f the or gani m is u d in th me lium After inc l ati n gr wth of the m ro lum in licat citrate utiliz n

Th f ll w ng re tion patte n a e on dered typ l f r the m re mp tant g nera of E terob te acea

E	I d l	M thyl ed	V ges- Prosk	C trate
E h chia	±	+	−	−
A robacte	±	−	+	+
Prot us	±	+	−	±
Salmo ll	−	+	−	+
Shig l		+	−	−

± d t tı th be pos t gat

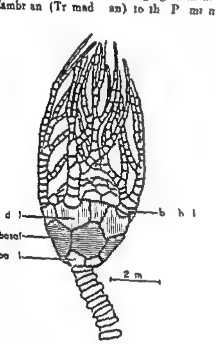
Th a e h w e m ny e c ption f om tand d hı h e ely e t ct the t o om a d dı g t c l e of thı t f test Se BACTER OLOGY MEDICAL CULTURE TECHNIQUE

[A J W]

B bl phy So ty f Ame a B t r logıst *M n l f M b l gı l M th ds* 1957

Inadunata

An t ct b la f talk d C ın dea e mprising m 00 f al ge ra angı g fr m th Upp Cambr an (Tr mad an) to th P m n



A d g m f Cy th d cy l d te d h w g th m pl t (Aft F B th 1900)

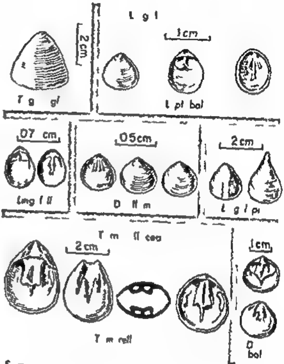
Th (3-5 o mo e) w mpl tely f e nd ı n w y n po ted ı t th alyx Th y w r the b hed mple d omet m bor p n les Th m th a d ml lacral gr s w u u lly oofed o by s of mall pl t a d tl t gm n wa ı d by pl te Th lyx wa th r m ocy lı r d cycl c w th c n picu d l nd b sal nd all th th c l pl tes e tu ed t g th r ınt g d y t m I som f m

the an s lay at the upper end of a l ng plated ph n r s ng f om the tegmen The gr up contains the oldest ecognizable cr noid *De d ocr us* fr m the Tr madoc an of Wale *See* CRI OIDEA

[H B F]

Inarticulata

A cla s of the phylum Brachı p da characteriz d by ha ng n art culatı g pro e u h a *teeth* and sock ts al ng the c rdinal ma g n or hinge

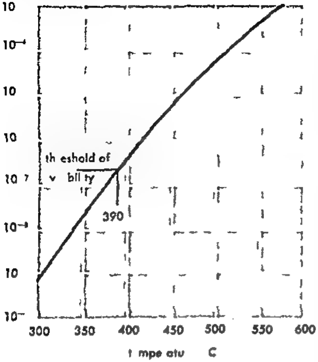


S m p t t s f art c lat B h pod (F m R C M C G L l k d A G F ch l rt b t F l M G w-H ll 1952)

I or if pr t th y re r diment ry Th tw l a e op n d and lo d by muscle ct n nly Tw de s a recog ed the Atremata and Neo-t emata A artı ulatı n a ly fu ct al ı *Sp dyl b lus* and *T m lla* both m mbe s of th In rt ulat and ha dly f n t n l n *A t g na nd S hızophalıs* wh ch a e A t c l ta a comm n r g for both gr ups s sugge ted The Inart c lata a g f o n the Camb to Recent [K H]

Incandescence

The em s on of ı ble r d t o hy a l t body t th etically perfect ad t ll d a bl k l dy will m t d a t ene gy rd ng t Pl nck radı t on l w t a y temper t e P dı t o f tl ı u l b ghtn s q es add tı nal con ıde t o f th e tıv ty of th ye and the rad t n w ll be ı bl ly f t mp atu of th bla k b dy wh h abov the m n m m The elat n l twe b gl tne s a d t mp r tu e ı pl tted ı th fig e A h wn th mı m m t mp at r for ı d cenc f the d rk ad ıted eye bo t



Relat on between br ghtness of a black body a d tem pe atu e

Approximate color temperatures of common light sources

So c	Color t mpe at e K
Ca ll	19
K ro in l n p	000
Con t gst n fl ment 100	
w tt l t l gl t l lb	800
C rbon	4000
S	800

390 C Under the e ideal ol erving condition the incande cence appears a a cc lorle glow The dull red light commonly a ciated with incande cence of ol ject in a lighted ro m requires a tem perature of al out 500 C See BLACK BODY HEAT RADIATION VISION

Not all ource of ligl t are incande cent A cold gas under electrical excitati n may emit light a in the o-called ne n tul e or tl e l w pre ure mercury vapor lamp Ultravi let light from mercury vapor may excite vi il le light fr m a cold lid as in the fluore cent lamp Lumine cence i the term u e l to refer t tl e emi i n of light due to cau e ther than high temperature and include thermolumi ne cence in whi h emi i n f previ u ly trapped energy occur on moderate heating See THERMO LUMINE CENCE see also FLUORESCENT LAMP MER CURY VAPOR LAMP

Flame are made luminou l y incande ent par ticle of carl on (a flame can l e made to pr luce inten e light l y tl e u e of a ga mantl of thoria ntaining a mall am unt of ceria Tl i mantle i a good emitter of vi il le light l ut a poor emitter f infrared ra liati n A les heat i l t in the long wa e the mantle operate at a high r temperatur than a l lack body w uld and hence produce m re inten e vi il le light

A u ful criterion of an incande cent o irce i n c l r temperature the temperature at wl ich a black body has the ame color although not neces arily the ame l rightne The color temperature of common light ources depend upon operating condition Approximate value are given in the accompanying table See COLOR TEMPERATURE INCANDESCENT LAMP [H W R]

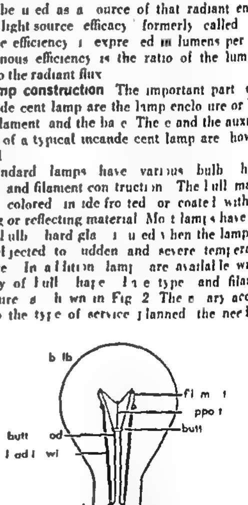
Bibliography M M Benarie Optical pyr metry below red heat *J Opt Soc Am* 47 1005–1009 1957

Incandescent lamp

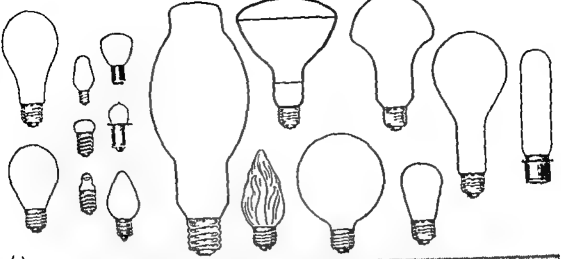
An electric lamp that produces light by heating a metallic filament to inten e heat by pa ing an electric current through it It is de igned to pro duce light in the vi ible portion (at wavelengths of 390–760 millimicron) of the electromagnetic pectrum The filament i prepared of pecial ma terials and is enclo ed in either an evacuated en clo ure or one filled with an inert gas In addition to radiation in the vi ible spectrum infrared and ultraviolet energy are emitted thus lowering the luminou efficiency of the lamp When either of the e radiation is accentuated hov ever the lamp may be u ed as a ource of that radiant energy The light source efficacy formerly called light ource efficiency i expre ed in lumens per watt Luminous efficiency is the ratio of the luminou flux to the radiant flux

Lamp construction The important part of an incande cent lamp are the lamp enclo ure or l ulb the filament and the ba e The e and the auxiliary parts of a typical incande cent lamp are hown in Fig 1

Standard lamps have vari us bulb hape ba e and filament con tructi n The l ull may l e clear colored in ide fro ted or coate l with dif fu ing or reflecting material Mo t lamps have soft gla l ulb hard gla i u ed when the lamp will l e ubjected to udden and severe temperature change In a l liti n lamp are availal le with a variety of l ull hape l a e type and filament tructure a h wn in Fig 2 The e ary accor l ing to the type of service planned the nee l for



Fg 1 Po t of the I ca d e t l mp (G l El c tr c Co)



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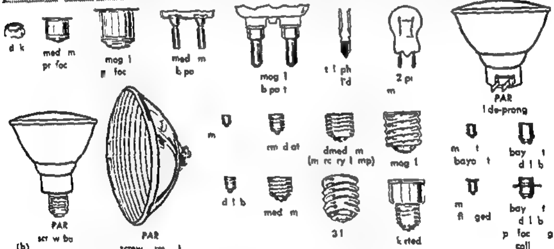
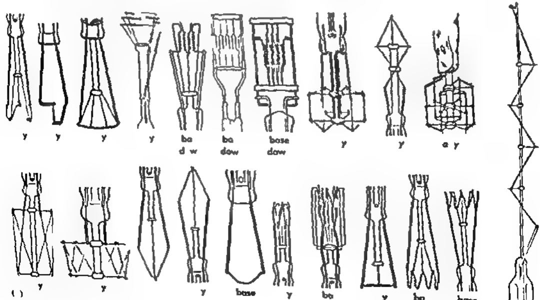


(b)



( )

Fig 2 V ia f l d sc t l mp ( ) B lb sh pe (b) L mp base ( ) Fl m t tr t (give b m g po io) (G l El ct C)

easy replacement and other environmental and service conditions

The efficient design of an incandescent lamp centers about obtaining a high *temperature at the filament* without the loss of heat or disintegration of the filament. The early selection of carbon which has the highest *melting point of any element (6510 F)* was a natural one. Carbon evaporates from its solid phase (sublimates) below this temperature, however, and it must be operated at relatively low temperatures to obtain reasonable life. Two other elements, osmium (melting point 4890 F) and tantalum (melting point 5250 F), claimed attention because they could be operated at a high temperature *with a longer life and less* evaporation. With the advent of ductile tungsten a nearly perfect filament material was discovered. Ductile tungsten has a tensile strength four times *that* of steel, its melting point is high (6120 F), and it has relatively low evaporation. Hot tungsten is an efficient light radiator. It has a continuous spectrum closely following that of a black body radiator with a relatively high portion of the radiation in the visible spectrum. Because of its strength, ductility, and workability, it may be formed into coils, these coils again recoiled (*for coil coil filaments*), and these again recoiled for cathodes in fluorescent lamps. If tungsten could be held at its melting point, 52 lumen/watt would be radiated. *Because of physical limitations*, however, 22 lumen/watt is the highest practical radiation for general service lamps. Some special lamps reach 35.8 lumen/watt. The higher the lumens per watt, the higher the filament temperature and the color temperature and the whiter the light.

Because the temperature of the filament controls the life of the lamp and its efficiency, it also controls the economics of lighting. For an economical installation, the factors affecting lamp life are weighed against the cost of the lamp and its in*stallation and the cost of operation. This type of* economic study, however, is rarely made of a lighting installation. The usual practice is to select a desired lamp size from the stock of the supplier for the accepted regional voltage.

Vaporization of the filament is reduced as much as possible. A small amount remains, however, and causes blackening of the bulb. The evaporated *tungsten particles are carried to the upper part of* the bulb by convection current. With the lamp in a base-up position the blackening is confined to the socket area and the light output is only slightly affected. In a base-down p*osition the blackening* reduces the output a few per cent. To reduce blackening, the inner atmosphere of the lamp is kept as clean as possible by use of a getter which combines chemically with the tungsten particles. In lamps in which a getter is not adequate, tungsten powder is enclosed in the bulb and used to scour the surface by shaking. In some lamps a grid is placed to attract and hold the evaporated tungsten particles.

When cement failures are likely because of the heat, mechanical fastening is used to hold the base to the glass. When large electric currents are present, either mechanical fastening or bipost construction is used. Bipost and prefocus bases allow accurate placement of the filament with respect to the equipment for which it is designed. There are two common failures of the lamp bulb: (1) in pro*jectors when the filament image is focused upon* the glass and the bulb blisters, and (2) when the hot bulb comes in contact with some low temperature medium and thermal cracks develop. To protect the electric circuit *from some lamp failure*, a fuse may be placed in the lead-in wire.

Lamp ratings. Lamps are built for various voltage conditions, the most common being 115, 120, *and 125 volts. High voltage lamps are designed for* ratings from 220 to 260 volts and low voltage lamps from 6 to 64 volts. Lamps for use in 525 to 625

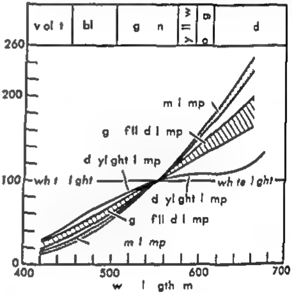


Fig. 3. Spectral energy distribution for important types of incandescent lamps.

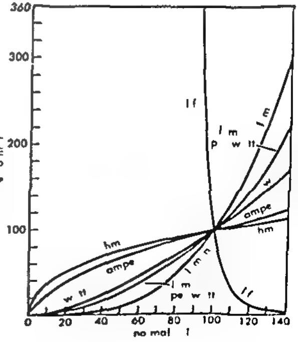


Fig. 4. Characteristic curves for incandescent lamps.

lt y tems desi ed to *operate in gr* ups f fi in ties acro th l n Ch i tma tr e l hts ar designed to perate in parallel r r s with e gh t l mp placed acr the l n St et l mp re f the e ie typ per tin n 6 6 amp l mp re f the e ie typ per tin n 6 6 amp ept i systems wl er ndi id al lamp tran f rmer a u ed w th lamp urrent of 15– 0 amp In se ies t t lighting y tem tl e nti nu ty f the electr al yst m i ma ned by a de ce that sh t c cu ts the lamp wl the fila ment b r t

Lamp characteristics Tw hara t ri ti f the ca d c nt lamp f parti ul int re t a e p t and of Fi e 3 h ws the el t n y n th art u e l r gi n for the major type of ca de e t l mp F gur 4 sh w the h ge f the r u per t ng ch racte st s th cha ge of ltage

At time it i ce a y to d t m ne l mp cha a t r t c u de th r than rm l co d ti Th f llowing fi e ts f qu t o with xpon nt g n Tabl 1 pe m t s lut on f r actual ervice d t mpa ed t n rmal op rat

$$\frac{l\ fe}{\mathrm{LIFE}} = \left(\frac{\mathrm{LUMENS}}{\mathrm{lum}}\right) = \left(\frac{\mathrm{LUMENS/WATT}}{\mathrm{l\ m\ \ /watt}}\right)^{s}$$

$$= \left(\frac{\mathrm{VOLTS}}{\mathrm{lts}}\right) = \left(\frac{\mathrm{AMPERES}}{\mathrm{mpe\ e}}\right)$$

$$\frac{\mathrm{l\ m}}{\mathrm{LUMENS}} = \left(\frac{\mathrm{v\ lt}}{\mathrm{VOLTS}}\right)^{k} = \left(\frac{\mathrm{l\ m\ n\ /w\ tt}}{\mathrm{LUMENS/WATT}}\right)$$

$$= \left(\frac{\mathrm{tt}}{\mathrm{WATTS}}\right) = \left(\frac{\mathrm{mpe\ es}}{\mathrm{AMPERES}}\right)$$

$$= \left(\frac{\mathrm{hm}}{\mathrm{OHMS}}\right)$$

$$\frac{\mathrm{LUMENS\ WATT}}{\mathrm{l\ m\ \ \ \ tt}} = \left(\frac{\mathrm{LUMENS}}{\mathrm{l\ m\ n}}\right)^{f} = \left(\frac{\mathrm{VOLTS}}{\mathrm{lts}}\right)$$

$$= \left(\frac{\mathrm{AMPERES}}{\mathrm{mpe\ e}}\right)^{t}$$

$$\frac{\mathrm{ampe}}{\mathrm{AMPERES}} = \left(\frac{\mathrm{lt}}{\mathrm{VOLTS}}\right) \qquad \frac{\mathrm{w\ tt}}{\mathrm{WATTS}} = \left(\frac{\mathrm{lts}}{\mathrm{VOLTS}}\right)$$

T th q t tt ry fi t t k w th m l har t t f the l mp u h l fe lume l m n p watt lt mp re watt l hm f ll th h t t to b tud ed d b m l lt n S b t t t g to th l t th pe fi m l h te t (up pe c l tt a d th pe l dit s (l w l tt) w th the p p ponent f om Table l tl k w ch t t m y be det m ed Th pt t T bl l e f d at t m b t f p t l pu p se d f r orm l ltag s g th g ll uffi

T l i g es tl ff t p tag f p rat ng f nt l mp lel w mal lt g Al th gh l w lt ge d e c lamp lif th ec m fi f l gl t ad g t u h

Applications and special types In nd t l m l l d l ted f m y rv ce M i on m th ed t g l m a d th

Table 1 Exponents

	Gas filled	V
	3 86	3 8
b	1	7 0
d	13 1	13
	1 1	3 3
k	3 38	3 1
h	1 81	1 8
	19	
y	6	6 0
	7 36	8 36
f	0 541	0 5 0
g	1 81	1 93
j	3 40	3 33
t	0 541	0 580
	1 54	1 58

T bl 2 Typi l perform e f l ge l a d c t lamp b ed below r ted lt g

P ce t g f	m l pe t		
V lt g	Light tp t	W tts	E ll y
100 0	100 0	100 0	100 0
99	97 3	98 8	98
98 3	94 4	9 4	96 9
97	91 8	96 1	9 4
96 7	89	9 0	93 8
9 8	86 4	93 6	9 3
9 0	81 0	9 4	90 8
94	81 5	91	89 4
93 3	8 0	89 8	8 7
9 5	76 6	88 7	86
91 7	4 1	87 5	84 8
90 0	69 5	8 0	81 7
88 3	6 0	8 5	79 4
86	60 8	80 3	8
8 0	56 6	77 9	72 8
83 3	5	5	69 7

m t t t e l mp Spec al type l a e b en de el ped f ugh rvi e ppl cat n b ke o en us s v re br t ppl c tio h w a e lamp m lt ple l ght (th e w y lamp) gn lamps potl ght fl dl ghts and i ect ntr l lamps

Se e e t light lamps are de ign d w th hea y fil m nt Th c it p at s at a nst nt ur ent a d the oltag on the c r uit s adju ted t th n mb r f b rn g lamp s t ke p th u e t t t

R flect r type l mps ha th l ght c t l b ilt t the de f the lamp Th is do by out id l e ng w th the l er ng pl ced n any des d gi n f th lamp fac The r fle ti g face p tect d a d effe ti for the l f of the l mp

Proj t typ l mp h ve m ld d gla fle t il e ed i d the l n p ty w th th r a l a gl s co m ld d trol le ver The refl r a d th o e a *sealed* t g th r f m ng l mp with n te al refl t The parts e f h rd gl s d th lamps may b d f r tdon rti in floodl gl t a d p tl ght i tall *s Th al th* typ f l mp u d in the led be m h dlight f a tom b l l mo-

ea y replacement and other environmental and ervice conditions

The efficient de ign of an incande cent lamp cen ters about obtaining a high temperature at the fila ment without the lo s of heat or di integration of the filament The early election of carbon which has the highe t melting point of any element (6510 F) wa a natural one Carbon evaporate from it olid pha e (ublimate) below this tem perature however and it mu t be operated at rel atively low temperatures to obtain rea onable life Two ther element o mium (melting point 4890 F) and tantalum (melting point 5250 F) claimed attention becau e they could be operated at a high temperature with a longer life and le s evaporation With the advent of ductile tung ten a nearly perfect filament material was discovered Ductile tung ten has a ten ile trength f ur time that of teel it melting point is high (6120 F) and it ha relatively low evaporation Hot tung ten i an efficient light radiator it ha a continuous spectrum clo ely following that of a black body radiator with a relatively high portion of the radia tion in the vi ible pectrum Becau e of it trength ductility and workability it may be formed into coil the e coils again recoiled (for coil coil fila ments) and the e again recoiled for cathode in fluore cent lamp If tungsten could be held at its melting point 52 lumen/watt would be radiated Becau e of phy ical limitations however 22 *lumen/watt i the highe t pra tical radiation for* general ervice lamps ome special lamps reach 35 8 lumen/watt The higher the lumen per watt the higher the filament temperature and the color temperature and the whiter the light

Becau e the temperature of the filament controls the life of the lamp and it efficiency it al o c n trols the economics of lighting For an economical in tallati n the factor affecting lamp life are weighed again t the t of the lamp and it in tallation and the co t of operation Thi type of economic tudy however i rarely made of a light ing in tallation The u ual practice is to select a de ire l lamp size from the tock of the upplier for the accepted regional voltage

Vaporizati n of the filament i reduced a much a po ible A mall amount remain however and cau e blackening of the bulb The evap rated tung ten particle are carried to th upp r part of the bulb by convecti n current With the lamp in a ba e up po ition the blackening i nfined to the socket area and the light output is nly lightly affected In a ba e down p ition the bla kening *reduce the output a few per cent* To reduce blackening the inner atm phere f the lamp i kept a clean a p ible by u e of a g tter which c mbine chemically with the tung t n particle In lamp in which a getter i not adequat tung t n p wder i enclo d in th b lb and u ed to c ur the urface by *baking* In om lamp a grid i placed t attract and h ld the e ap rated tung ten particle

Wh n cem nt f ilure ar likely becau e of the h at me hani l fa t ni g i u d to h ld the base to the gla When large electric current are pres ent either mechanical fa tening or bipo t con *truction i u ed Bipo t and prefocu ba e all* accurate placement of the filament with respect to the equipment for which it is de igned There ar two common failures of the lamp bulb (1) in pro jectors when the filament image is f cu ed upon the gla s and the bulb bli ters and (2) when the hot bulb comes in contact with some low tempera ture medium and thermal crack devel p To pro tect the electric circuit from ome lamp failure fu e may be pla ed in the lead in wire

Lamp ratings Lamps are built for various v lt *age conditi n the mo t common being* 115 120 and 125 volts High voltage lamps are designed fo ratings from 220 to 260 volts and low voltage lamp from 6 to 64 volts Lamps for u e in 595 to 625

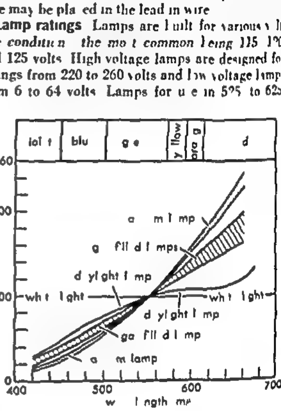


Fig 3 Spect al e e gy d st but on for importa types of i cand cent lamp

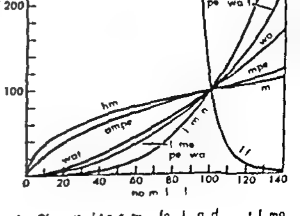


Fig 4 Ch act i t c c v fo i a d t l mp

It ystem are des gned t ope ate in group of fi e n erie cro s the l n Chr tm a tr e lights ar des gned to op at in parall l r m s r es with ght l mps pla ed acro the l ne Str et lamp ar of the e es typ operat ng n 6 6 amp ex ept in y tem whe e i di dual lamp t a sform s ar u ed w th lamp cu r nt f 15-20 amp In a r es t eet l ghti g syst m th t n ty f th elect cal system s m inta ned by a de ice that t-cir u t th lamp when tl e fil ment b rn out

Lamp characteristics Two ch racte t s f th in and t l mp of p rt c l r i te e t a e pe t on and ol r Figur 3 hows the el t e gy the atio s e l r r g on for the majo typ of i and t lamp Figu 4 h w the ch g f the var i p g character tic with a cha of lt ge

At t m t is ne ary t d t rmi l mp ch r t tics u d r th r th n mal e diti Th follo g fi e t of eq ati n w th e ponents n Tabl 1 pe mit luti f r a t l ervice co d ti ns a mpar d to n rmal op rati

$$\frac{\text{lfe}}{LIFE} = \left(\frac{\text{LUMENS}}{\text{l m s}}\right) = \left(\frac{\text{LUMENS/WATT}}{\text{lum ns/w tt}}\right)^b$$

$$= \left(\frac{\text{VOLTS}}{\text{olts}}\right) = \left(\frac{\text{AMPERES}}{\text{mpe es}}\right)$$

$$\frac{\text{lum}}{\text{LUMENS}} = \left(\frac{\text{lt}}{\text{VOLTS}}\right)^k = \left(\frac{\text{l me /watt}}{\text{LUMENS/WATT}}\right)^h$$

$$= \left(\frac{\text{tts}}{\text{WATTS}}\right) = \left(\frac{\text{ampe s}}{\text{AMPERES}}\right)$$

$$= \left(\frac{\text{hms}}{\text{OHMS}}\right)$$

$$\frac{\text{LUMENS WATT}}{\text{l m n att}} = \left(\frac{\text{LUMENS}}{\text{lum ns}}\right)^f = \left(\frac{\text{VOLTS}}{\text{olts}}\right)$$

$$= \left(\frac{\text{AMPERES}}{\text{amper}}\right)$$

$$\frac{\text{mpe s}}{\text{AMPERES}} = \left(\frac{\text{lt}}{\text{VOLTS}}\right) \qquad \frac{\text{watts}}{\text{WATTS}} = \left(\frac{\text{volt}}{\text{VOLTS}}\right)$$

T th q t o t ne es ar fir t to kn w th n mal h r t t f th l mp u h l fe l l m p watt l mp watt a d hm ll th ch ra t t r t be ind d und b m l o d t Sub t tuti g t t the q t the i fi n m l ha t (p pe - l tt) and th p l d t ll we l tt t th p pe e p n t f m Tabl l th u k n l a te t m y be d te m ned Th e po t m Tabl l a ch ged t t ne but f p t l p p e d f r rm l ltage ge th e g n will uffi

T bl g th ffe t p entag f p r ng d nt l mp bel w n m l v lt g Al eco m a fi e f l gl t d es agan t u h p tt

Appl cat ons and special types I a des nt l mp ha bee dev l ped f m ny rv e M t omm a th ed g l ers nd the

Tabl 1 Expon nt

	C s-filled	V m
	3 86	3 8
b	7 1	7 0
d	13 1	13 5
u	1 1	3 3
k	3 38	3 51
h	1 84	1 8
	19	
y	6	6 0
	7 36	8 36
f	0 41	0 5 0
g	1 84	1 93
j	3 10	3 33
l	0 41	0 580
	1 54	1 58

Tabl 2 Typ cal perform f ta g l ca d sce t l mps burned below ted voltag

P	tag	f rm l pe t	
V lt g	Light tp t	W tt	Eff y
100 0	100 0	100 0	100 0
99	97 3	98 8	98
98 3	94 4	9 4	96 9
9 5	91 8	96 1	9 4
96 7	89	9 0	93 8
95 8	86 4	93 6	9 3
9 0	84 0	9 4	90 8
[illegible]	81 5	91	89 4
93 3	8 0	89 8	8
9 5	6 6	88 7	86
91	74 1	87 5	84 8
90 0	69 5	8 0	81 7
88 3	6 0	8 5	9 4
[illegible]	60 8	80 3	8
8 0	56 6	77 9	8
83 3	5 0	7 5	69

m atu e l mp Spec al t pe h e b en de l ped for o gh ers e ppl cat n b ke-o n u e e brat n ppl c t on sl we e lamp mult ple light (thr e w y l mp) gn lamps p tlight fl dl ght nd n ect co t l l mp

Ser tr t l ghtin lamps re des gn d w th h a y flam nt The cu t e t s at con tant r at d the oltage on the c r uit i adju ted t the umbe of bu ng l mps a as t k ep th e e t consta t

R flect typ lamps ha the light ontrol l u lt into the de gn f th lamp Th s d ne by t d l g w th th l e g plac d on any de r d regi of the lamp s rf c The reflect ng urf c i p te ted a d effect for the l f f th lamp

P oject r type l mp l a molded gla s refle to s th d n ide th l mp ca t) with ither a cl a gl s co r a m lded control l n co er The fl t and the co er ar led t gether fo mi g a lam p with nt rn l refl tor The p ts re f ba d gl s nd the lamp m y be u d fo o td r rvi e in floodlight a d potl ght i talla t Thi al th type of l mp ed n the led b am h adl ght f a tomob l s lo mo-

tives and airplanes. A high degree of accuracy—just short of optical accuracy—is achieved by molding the contours of the reflector, thereby obtaining accurate beam control. With this sturdy structure the filament can be positioned for the best use of the lens, and the lamp has little depreciation during its life. Being constructed of hard glass, it lends itself to high wattage use.

Miniature incandescent lamps are used in many fields and in many pieces of equipment, from the ordinary flashlight to the "grain of wheat" lamps used in surgical and dental instruments. These lamps are designed to give the highest efficiency consistent with the nature of the power source employed.

Special picture projection lamps are designed for accurate filament location in the focal plane of the optical system, with the filament concentrated as much as possible in a single plane and in a small area. These precision lamps use a prefocus base for accurate positioning of the filament with respect to the base. Projector lamps run at high temperatures, and forced ventilation is frequently required.

A special class of lamp is designed for the photographic field, where the chief requirement is actinic quality. Frequently the most important rating is the color temperature, with little regard for economic efficiency or life. Photoflood lamps give high illumination for a short life, obtaining twice the lumens from high filament temperature and high color temperature with three times the photographic effectiveness. The daylight blue photoflood lamp gives a very white light at 4800 K color temperature at 35.8 lumen/watt.

For other types of incandescent lamps *see* ARC LAMP; INFRARED LAMP. [J.O.K.]

Bibliography: Illuminating Engineering Society, *IES Lighting Handbook*, 3d ed., 1959.

Incendiary

One of a number of flammable materials and devices that are used to set fire to tactical and strategic targets, such as buildings, industrial installations, and fuel and ammunition dumps. Flame warfare extends also to antipersonnel use in the case of flame throwers and fire bombs.

Modern incendiaries can be classified as either those which owe their effect to a self-supporting chemical reaction or those which depend on atmospheric oxygen to support combustion.

Mechanized flame thrower.

Metallic incendiaries. Thermite is a mixture of powdered iron oxide, Fe_3O_4, and powdered or granular aluminum. When heated, the following reaction occurs:

$$Fe_3O_4 + 2Al \rightarrow Al_2O_3 + 2Fe$$

This produces a temperature of about 2?00 C and melts the iron formed, which in turn easily ignites any combustible material with which it is in contact. The reaction is self-sustaining.

Metallic magnesium, igniting at about 600 C, requires oxygen to support combustion. Once started, the fire is extremely difficult to put out. Water is decomposed by burning magnesium and adds hydrogen to the combustion. Burning is stopped only by excluding oxygen or by cooling the metal below its ignition temperature. Incendiary bomb casings of magnesium are usually ignited by a thermite core.

Petroleum incendiaries. These are based on gasoline as a fuel. The gasoline may be either straight or mixed with other petroleum fuels. It must, however, be thickened to be an effective incendiary. This thickening is necessary to confine the burning material to the target and, when used in flame throwers, to increase the range of the ejected rod of fuel and to prevent its being consumed before reaching the target. Thickened fuel is sometimes called jellied gasoline.

One of the first practical fuel thickeners was Napalm, a mixed aluminum soap in which the organic acids are derived from coconut oil (50%), naphthenic acid (25%), and oleic acid (?%). It may be used in quantities ranging from ? to 12%, depending on the thickness desired. Gasoline thickened with Napalm becomes a firm jelly when undisturbed, but in motion, such as when forced through a flame thrower nozzle, it acts as a viscous liquid. This thixotropy is characteristic of all thickened fuels.

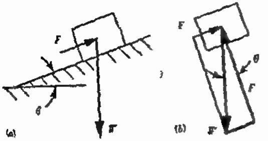
Flame throwers are devices which force petroleum fuels through nozzles, igniting them as they emerge. The driving force is usually compressed air carried in a small tank which is an integral part of the device. Portable flame throwers carried by soldiers have a range of over 50 yards under ideal conditions. Mechanized flame throwers mounted on military vehicles can throw fuel over 150 yards. Flame throwers are primarily antipersonnel weapons.

Other incendiaries. White phosphorus, which ignites spontaneously in the presence of atmospheric oxygen to produce a dense cloud of phosphorus pentoxide, has [illegible] as an incendiary although it principally [illegible] as a smoke producer. Bursting [illegible] grenades throw [illegible] small drops of burning white phosphorus [illegible] effective as antipersonnel incendiaries. See CHEMICAL WARFARE; FIRE EXTINGUISHER; SCREENING SMOKE. [S.D.]

Bibliography: [illegible], *Incendiary Warfare*, 194?; U.S. Department of the Army, *Military Chemistry and Chemical Agents*, Technical Manual TM 3-[illegible], 15 August 195?.

Inclined plane

A pl n urfa ncl ned an a gl with th l ne f cti n of th force th t i t b exerted o o e m Th u al applicat n i illustrat d i the



F p l f ( ) we ght g o i (n d pl d the lut i m l f c (b)

d agr m A l ti ely m ll force cti g parallel to the rf c h lds n object in pl e or mo es it at c n t nt peed

In th f ee-body d agram th e f es act o the object when n f i ti n s p e t The f es a e t w ght W the f e F p r llel to the urf c d a f r F m l to th n fa e Th umma ti n of th f es a t g n a y d e t a body in st tic eq l b m equ l e the ef r th mmat o f f par llel t and forces rmal t the s rfa e a e

$$F - W \sin\theta = 0$$
$$F - W \cos\theta = 0$$

A f e l ghtly g t tha W n θ mo e th b- ject p th in l e, but th i l ned plane pp rts th g t p rt f th we ght f the l ject. The p pal e f th l ed pl ne a amp for m ng good fr m o e lev l t a the Wheels ma be dded t th bje t t b a ed t decr e f t n but th p e ple r ma th ame Th edg nd sc w r l ely el ted t the in l ned pl n nd f d wid appl t n S SIMPLE MA CHINE [R M PH]

Inclinometer

A n t m t fo m g m gn t d p r i f n t wh h defi d th a gle b tw n the m gn t fi ld t nd th h ntal pl ne l th f m f impl d p n dle th in tru m t th ted mech n ll b la ed bar m gnet m u ted h r i l b g Wh n o ted so th t t pl e of t ti n n the m g t m d n th eedl l gn it lf w th the d ect f the m gnet fi ld a d ndi ate n cul r al the gle f d p It s n d p n pally m n y g wh e th mt l ha e high p t i m g t m t ial

Th d p i l lso es b l n ed eedle b t of fi i t n nd p o ded with ac u ately g d nd pol hed nd halt be r ng b n t l gat pl tes Th d ecti n f m t zat on f h rdl rtifi ally e ed e al t mes d g ect f b rsat n to ed e th tes d l eff ct of mechan cal unbalance and the positi ns of the ends of the needles a e read with micro- scope mou ted a verni r equipped vertical cir cle Th d p circle having an ac acy of n better th n 3-5 of ar h s l rg ly been repla ed by other in truments n magn t c ob servatories and for first q al ty m gn tic fi ld w rk (s e EARTH INDUCTOR) [J H NE]

B bli graphy See MAGNETOMETER

Inclusion blennorrhea

An inflammat on of th o juncti a of th new b rn s eye cau ed by a irus of l rge p rticle size ident al in mo ph l w th the tr homa i us The nfect o s u its of th n nb cterial on junct it s are lementary bod e wh ch f rm cyto- pla m c l ons in the conjun ti al cell The d fferenti ti n of th s d e s from tr choma rest th d m l rity f th linical p tures only t a h ma g es r t carr ng of th l ds and pa n s

So-c lled wimm ng pool c nju cti iti s of the ame et ology a njunct it s of th ewborn Si ce the res rv r eem t be the ge ital tract wat r f wimming p l i sa d t be infe ted by di ch rg s fr m the ge ital tract of infected bath Chlori ation f water elim nate th s urce f d it o j cti t l fecti n of the newborn s eyes c mes f m the ge ital t ct f the mother

Sulf n m de en by mouth re eff tive ag n t w mm ng pool c ju cti ti top cally appl ed s lfad az ne i tment s ccessf l n t at m t and pre e ti n in nfant Se VIRUS [K F ME]

Inclusion bodies (virus)

Abnormal tru t re which appear w thin th cell n cle th yt pla m or both d i ng the o ır of u mult pl ati n Th y u lly ha e ch a ter i ti tai i g p op rt e In gen al th inclu n l d e con erned with the d vel pm ntal proc e of the i u In me v r i fe t s such a mollu um ntagi m in l ion bod may be mply m s l matu i virus part cles I th f t s (h pes impl) typ l n lu on bod d n t appe r until aft r the iru h m lt pl ed a d the e n l ion m y b e n ant of th pr s of a m ltiplic t n S HERPES IM LEX

Th prese f i lu on bod is often im p rta t in d g A cytoplasmic i clu ion n r v cell the N gri body p thog om fo r b es S RABIES VIRUS [J L.M]

Incompressible flow

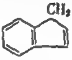
Fl id m t o w tho t h ng n den ty F p a t l pu pose l qu d as med t fl w inc m p es bly At l w eloc ty th s ne rly the a h e fo l qu d ab upt ch ng s in loc ty prod ce mpr i n r r f ti n (WATER HA I IER) U ll liq d flo u d th tion of gra ty t ce py th l w r port f an op n l Th p p ty s t k n as th d tingu hi g f tu f a l q d A g s, i tr i flow com

pressibly to occupy any closed space to which it is confined regardless of the initial volume of gas and space This property distinguishes a gas As with liquids slow flow of a gas is closely approximated by assuming it to be incompressible For example at airplane speeds below about 200 mph the flow of air about a body can be analyzed as incompressible Usually the dividing line is taken at a Mach number of approximately 0 3 Below this velocity flow is considered incompressible In this region the Reynolds number provides a measure of flow characteristics The approximation brings several simplifications Density and temperature are assumed to be constant during incompressible flow Like frictionless mechanical motion incompressible flow is a useful engineering concept but not an accurate description of reality *See* AERODYNAMIC FORCE COMPRESSIBLE FLOW FLUID FLOW PROPERTIES MACH NUMBER REYNOLDS NUMBER

[J F MA]

Indene

A colorless liquid hydrocarbon (also called benz cyclopentadiene) which boils at 181 C and freezes at −2 C It is usually obtained from the light oil fraction (boiling point 178–182 C) pro



Indene C_9H_8

duced in the carbonization of coal but it is also obtained by the pyrolysis of certain petroleum fractions

Indene resembles cyclopentadiene in that one hydrogen of the methylene (CH_2) group may be replaced by sodium Indene may be oxidized to phthalic acid or reduced to indan (C_9H_{10}) In the presence of acid indene polymerize Copolymer with benzofuran have been manufactured on a small scale for use in coating and floor covering *See* POLYNUCLEAR HYDROCARBON [C K B]

Index fossil

Any fossil which identifies and dates the rock strata or succession of strata in which it lie The name of the index fossil is used to designate the strata (zone) containing it such as the Cambrian trilobite zones and Ordovician graptolite zones The term guide fossil is applied to any fossil that is useful for purposes of identification or correlation The usefulness of both guide and index fossils depend upon their restricted vertical (stratigraphic) range wide areal geographic distribution abundance and distinctive characteristics *See* FOSSIL *see also* STRATIGRAPHIC NOMENCLATURE [N A B]

Indian Ocean

The boundaries of the Indian Ocean adopted by the Pan Indian Science Association in 1953 include the Red Sea (area 438 000 km²) Persian Gulf (239 000 km²) Andaman Sea (790 550 km) Arafura Sea (1 391 000 km) and Bass Strait (75 000 km) also that part of the Southern Ocean between 40 S and the Antarctic Circle and extending from 20 E in the west to a line in the east along the Balleny–Macquarie–Mill Rise Ridge to South Cape in Tasmania (23 301 000 km) The total area is 77 948 000 km (1 km = 0 3861 mi) The ocean sector north of latitude 50 S is discussed below *See* ANTARCTIC OCEAN

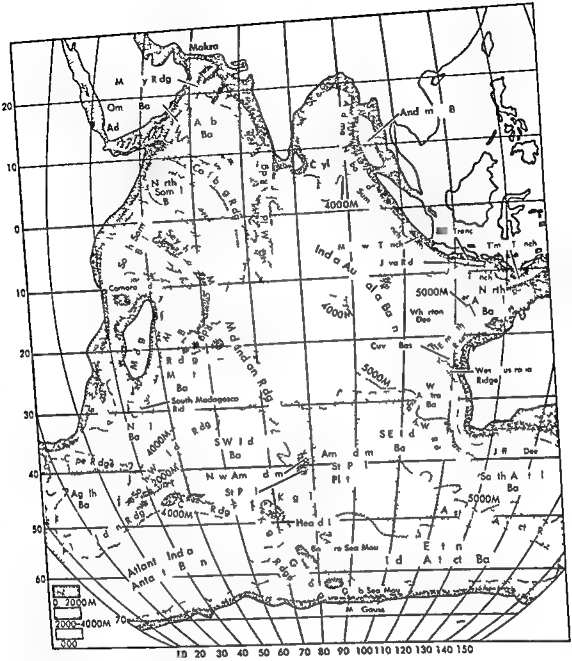
Ocean floor The floor of the Indian Ocean is divided longitudinally by the Carlsberg Mid Indian Kerguelen line of ridge (Fig 1) North of the island of Rodriguez (20 S) the general depth of the ridge system is 2300 2700 m with a least depth of 836 m Southward it rises to the islands of New Amsterdam St Paul Kerguelen and Heard West of this line the marine sediments are chiefly globigerina ooze eastward chiefly fine red clay of terrigenous origin with volcanic deposits present in the Indonesian arc The deepest basins and trenches occur east of this line of ridge and include the Wharton Deep 6460 m and the Sunda (Java) Trench 7455 m Little is known of the deep circulation in the basins of the Indian Ocean

Temperature and salinity In the oceanic area of the Indian Ocean data are sufficient to show general seasonal differences in the distribution of surface temperatures and salinity but not to show detailed aspects of annual variation In coastal areas the amount of detailed information is much greater but often is not sufficient to show the distribution of temperature and salinity because of the greater variations which occur there

Surface temperatures The mean surface temperature in February (Fig 2) shows the influence of the southern shift of the thermal equator that of August (Fig 2) shows the northward shift The isotherms run generally from west to east and are not greatly diverted by the ocean currents As in the other oceans the temperature of the deep water decreases from 3 C at about 2000 m to 1 C at the bottom

Surface salinity The Arabian and Red Seas are areas of high surface salinity Arabian Sea surface water extends southward toward Madagascar (Fig 3) In the south a belt of high salinity water extends from South Africa toward Australia reaching salinity values higher than 35 parts per thousand (‰) near Australia Owing to river runoff and high rainfall salinity is less than 31 ‰ in the Bay of Bengal and west of Sumatra The permanent extension of the area of low salinity shown south of Java in Fig 3 is [illegible]

Surface currents South of latitude 10 S surface current form [illegible] counterclockwise circulation which continues throughout the year In the latitude of the 40 the west wind [illegible] maintain an eastward drift of surface water Part of this drift continues eastward south of Australia but the main current [illegible] toward the [illegible] major part of the South Equatorial Current which returns toward the African Coast The current becomes the Agulhas stream which flows southward between



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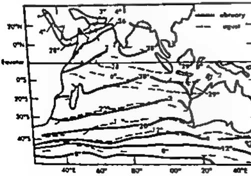
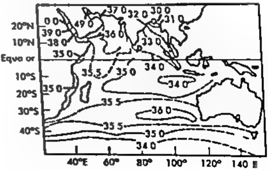


Frg 2 M f t mp t (C) F b ry d A g



Fg 3 S l ty rth m mm (Aft H U S d p)

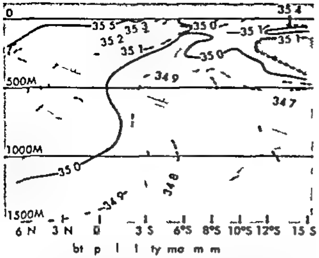


Fig 4 Relations of water masses in the upper 1500 m of the Indian Ocean from 6 N to 15 S along 50 E based on records of salinity obtained in 1935 by the French vessel *Nosel* (*After Tchernia Lacombe and Guibout 1958*)

Madagascar and Africa In the southern winter the South Equatorial Current also contains water entering north of Australia from the Pacific Ocean In the southern summer this contribution ceases *See* SOUTHEAST ASIAN WATERS

North of latitude 10 S the circulation is determined seasonally by the prevailing winds In February and March when the northwest monsoon prevails the North Equatorial Current (east to west) is well developed and an Equatorial Counter Current (west to east) is present between 2 S and 4 S between the Gulf of Aden and 5 S a current flows to the south In August and September under the influence of the southwest monsoon the North Equatorial Current disappears and is replaced by the Monsoon Current (west to east) The Equatorial Counter Current forms part of the general eastward surface flow in the northern Indian Ocean during this season and a stream (the Somali Current) runs northward along the African Coast from 10 S to 10 N

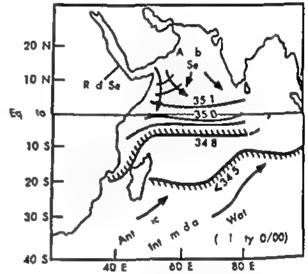


Fig 6 Southern limit of Red Sea and Arabian Sea water and northern limit of Antarctic Intermediate Water at 1000 m (*Adapted from J LeFloch 1951*)

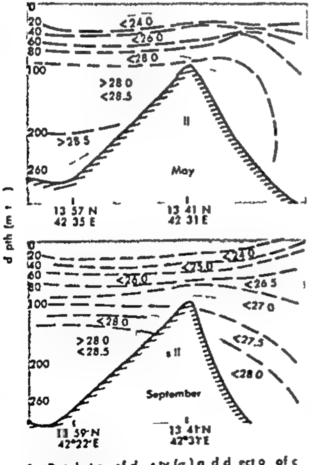


Fig 5 Distribution of density (σ) and direction of current at sill of Red Sea in May and September (*After E F Thompson 1939*)

Subsurface circulation Little is known about the subsurface circulation north of 50 S because ocean station data for depths greater than 1000 m are sparse From the available data however and from data obtained in the upper layer it is possible to show the interactions of the more important water masses namely that originating in the Red Sea Arabian Sea area and that originating as Antarctic Intermediate Water (Fig 4)

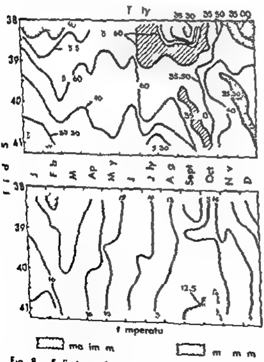
A high rate of evaporation in the Red Sea (length 1000 mi width 150 mi maximum depth 2800 m) leads to the formation of relatively dense bottom and intermediate water (temp <2 C salinity >37‰ density σ > 7 0) This water flows into the Indian Ocean over the sill or ridge near the entrance of the Red Sea (Fig 5) The flow is irregular and greater in the northern winter than in the summer This water along with that formed in the Arabian Sea spreads easterly toward longitude 80 E and southerly toward latitude 15 S at intermediate depth (1000 3000 m) mixing with surrounding ... water ... (Fig 6)

Antarctic Intermediate Water (salinity 33 8 ‰ temp 2 2 C) formed at the Antarctic Convergence flows northward in the Indian Ocean In the western area it ... from 1000 ... to 300 m at 8 S and ... its identity ...

80 F a d 100 E t c nt nues at about 1000 m t 12 S d then ri es sharply t ward the surface (F g 6) [K]

Bass Strait Th Ba s Str it li between the Au tr l an mainland a d th isla d f Ta man a It i imp rta t way e nn etm ea tern and west er A t al n port nd the ce ter f th p inc p l b rrac d and school shark fisl er e of Au tra l It h an pp oximate are 145 000 q mi, with

F g 7 Ch rt f B St t h w g p l g t d d t d m th f t ory sets. D t f m A t l P l t d d fi b ttle l (C.S.I.R.O D F h O ea g C ll A st l)



mo im m m m m

F g 8 Sal ity d t mp t e ch g of g th h A B l F g 7 d g 1957 (D t f m C.S.I.R.O Div F sh O ea og C ll A st l)

an verage d pth of 60 m *There s a deep cl annel* (75–80 m) through the e tral and northwest ec tions (F g. 7) D ring the w nter and early pring a g neral mo em nt of Southern Ocean water nt Ba s St a t ccur through the western appr ache By No emb to December howe e c ntrary ts e pecially b tween Kin I I nd a d th V i t r an mainland all w the ingre s f om the ea t of sub-tr p al wate s fr m outhern New South Wale and e te n T m n a To m ext nt the e ha g i i cul t on d termine the ea onal a l ty temperature ch ng s (Fig 8) Dur ng Apr l to Ju Ba Str t water ha e tl alin ty (35 40–35 50 ‰) and temperatu e (14–16 C) typical of South rn Ocean wat r we t of Ta man a at th t time Fr m July to O t ber the h he t ali ity waters (≈ 35 60) flow i to B ss Strait from South Au tralia Low sal n ty wate (35 00–35 30 ‰) oc ur du ing the spring and summer along the V ct r an coa t b t in general their effect o Bas St ait i l ght The d scharge of large quant t es of water reta ned u t l early ummer as ow d ic i the m ntain reg ns f the major T sm n an ri e f rms a la ge b dy of Ta m n an coa tal wate wh ch ha a ma ked effect a alin ty v l es in the Bass Stra t d ring Decembe nd J nu ry S e PACIFIC OCEAN [D J R]

Bibliog aphy J N Jenn ng Th submarine topography f Bass Strait *P c R y Soc (V c tor a)* n l 71 *pt* 1 1959 M J P llak Frequency di tr b ti n of p tent al temper t re nd l t n the Indi n O ean *D p-S a R ea ch* 5 128–133 1958 G Schott *G g ph d s I dis h a d Still O s* 193

Indicator acid base

A ubstan that rev l th ough characte i t c c l ha g tl deg e of idity r b si ity f l t o s Indicat r a e we k org ac ds or ba es wh ch x t in mo than o e truct ral form (tautom) f wh h at lea t one form i olored Inten e ol de ble that y l ttl d at s need d th i d e t r it elf w ll thus not ffe t th acid ty of the lution

Th equ l b m r a t n of d cator may b reg ded typ ally by gi ng i th f rmula HIn It d iate t H nd In ions a d equilib-um w th taut m r I H whi h i e the a n ele t l t or at m t i n zes ery l ghtly In th ll equ l l i m

$$\underset{\text{(I)}}{\text{InH}} \rightleftharpoons \text{HIn} \rightleftharpoons \text{H}^+ + \underset{\text{(II)}}{\text{In}^-}$$

th mpl fy g as umpt on th t the i d c t r e t nly in *form* (I) and (II) leads t no d ffi ulty The add t n f e d n ll c mpletely c n ert th ind cato i *f rm* (I) whi h the ef r alled th c d f m of the i d at lth ugh t s fun i n g a a ba A hyd o d b e co verts the d t to f rm (II) w th the f rmati n of water th is alled the alk l f rm For th equ l b-r um between (I) nd (II) the q l b m n ta t s

$$K_I = \frac{[H^+][In^-]}{[InH]}$$

In a manner similar to the pH designation of acidity, that is, pH = −log [H⁺], the K_I is converted to pK_I with the following result:

$$pK_I = pH - \log \frac{[In^-]}{[InH]}$$

It is seen that the pK of an indicator has a numerical value approximately equal to that of a specific pH level.

Use of indicators. Acid-base indicators are commonly employed to mark the end point of an acid-base titration or to measure the existing pH of a solution. For titration the indicator must be so chosen that its pK is approximately equal to the pH of the system at its equivalence point. For pH measurement, the indicator is added to the solution and also to several buffers. The pH of the solution is equal to the pH of that buffer which gives a color match. Care must be used to compare colors only within the indicator range. A color comparator may also be used, employing standard color filters instead of buffer solutions.

Indicator range. This is the pH interval of color change of the indicator. In this range there is competition between indicator and added base for the available protons, and the color change, for example, yellow to red, is gradual rather than instantaneous. Observers may therefore differ in selecting the precise point of change. If one assumes arbitrarily that the indicator is in one color form when at least 90% of it is in that form, there will be uncertain color in the range of 90% to 10% InH (that is, 10% to 90% In⁻). Upon substituting these arbitrary limits into the pK equation, it is seen that the interval between definite colors is from

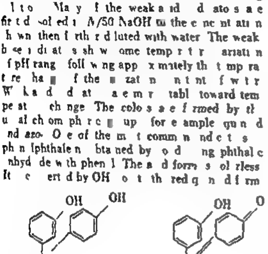
Common indicators

Common name	pH range	Color change (acid to base)	pK	Chemical name	Structure (acid or base)	Solution
Methyl violet	0.–5.6	Yellow to blue violet to violet		Pentamethylbenzyl pararosaniline hydrochloride	Base	0.–% in water
Metacresol purple	1.–.8; 7.3–9.0	Red to yellow to purple	1.5	m-Cresol sulfonphthalein	Acid	0.3% in N/50 NaOH, dilute to 0.01%
Thymol blue	1.–.8; 8.0–9.6	Red to yellow to blue	1.	Thymol sulfonphthalein	Acid	0.93% in N/50 NaOH, dilute to 0.01%
Tropeoline 00 (Orange IV)	1.4–3.0	Red to yellow		Sodium p-diphenylaminoazobenzenesulfonate	Base	0.1% in water
Bromphenol blue	3.0–4.6	Yellow to blue	4.1	Tetrabromophenol sulfonphthalein	Acid	1.39% in N/50 NaOH, dilute to 0.01%
Methyl orange	.8–4.0	Orange to yellow	3.4	Sodium p-dimethylaminoazobenzenesulfonate	Base	0.1% in water
Bromcresol green	3.8–5.4	Yellow to blue	4.9	Tetrabromo-m-cresol sulfonphthalein	Acid	0.1% in 20% alcohol
Methyl red	4.–6.3	Red to yellow	5.0	Dimethylaminoazobenzene-o-carboxylic acid	Base	0.5 [illegible] in N/50 NaOH, dilute to 0.01%
Chlorophenol red	5.0–6.8	Yellow to red	6.	Dichlorophenolsulfonphthalein	Acid	0.8% in N/50 NaOH, dilute to 0.01%
Bromcresol purple	.–6.8	Yellow to purple	6.4	Dibromo-o-cresolsulfonphthalein	Acid	1.08% in N/50 NaOH, dilute to 0.01
Bromthymol blue	6.0–.6	Yellow to blue	.3	Dibromothymolsulfonphthalein	Acid	[illegible] in N/50 NaOH, dilute to 0.01
Phenol red	6.8–8.4	Yellow to red	8.0	Phenolsulfonphthalein	Acid	0.71% in N/50 NaOH, dilute to 0.01%
Cresol red	.0–3.0; .–8.8	Orange to amber to red	8.3	o-Cresolsulfonphthalein	Acid	[illegible] in N/50 NaOH, dilute to 0.01
Orthocresolphthalein	8.–9.8	Colorless to red			Acid	0.04 [illegible]
Phenolphthalein	8.4–10.0	Colorless to pink	9.		Acid	1% in [illegible]
Thymolphthalein	10.0–11.0	Colorless to red	9.9		Acid	0.1 [illegible]
Alizarin yellow GG	10.0–1.[illegible]	Yellow to [illegible]		Sodium p-nitrobenzeneazosalicylate	Acid	0.1% in warm water
Malachite green	11.4–13.0	Green to colorless		p,p'-Benzylidenebis-N,N-dimethylaniline	Base	0.1 in water

$$pH = pK + l \frac{10}{90} \quad t \quad pH = pK + l \frac{90}{10}$$

Thu the pH certa nty of the i d cator s from pK + 1 t pK − 1 (approx mat ly) a d pK ± 1 s c lled th range f the nd t r Th e p r m n tally b rved ange m y d ffer f om tl s p edi t n m wh t b a f a i t n c lor n t n ty

Examples The a company ng tabl l sts ma y of the c mmo d cat r the r chem l names pK v l e r ges f pH nd d r ct ns f r m k g l t o Ma y f the weak a id d ato s a e fir t d sol ed i N/50 NaOH in the c nc nt ati n h wn then f rth r d luted with water The weak b se i di at s sh w ome temp r t r ariati n f pH rang foll w ng app x mately th t mp ra t re ha g f the i zat n n t nt f w t r W k a d d at a e m r tabl toward tem pe at ch nge The colo s a e f rmed by tl u al ch om ph r c g up for e ample qu n d nd azo O e of the m t comm n nd c t s ph n lphthale n bta ned by o d ng phthal c nhyd de w th phen l The a d form s ol rless It c ert d by OH o t th red q n d f rm



Othe i d t r u h s m thyl o a ge a d m thyl red are sod um s lts f azob nz ne d ri t es on t i i g ulf n nd a b xyl groups e pec t ely S e ACID AND BASE HYDROGEN ION TITRATION

[A L H]

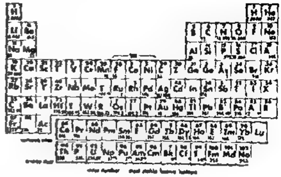
Indium

Chem l l m t numbe 49 ndi m In Il s at m w ghi 114 8 d i memb f gr p III nd th fifth pe i d f the p d t ble It v l n e fig rat 5s 5p wh h lt i ma m m x d t o t t f III Comp ds f th x d t n t i l nd app nt ox l t te II In i 0 81 A

l reported Th Gold hm dt d u fi th

I d um occ r in the arth ru t to the te t f about 1 × 10 f t s w d ly d t buted in s m y a 50 m l d o es, rt ul ly tho e f n wh h it may mo t to 0 1

Th tu l ses of nd m f w a r flected by a t t l d mest produ t l 87 600 (t oy) i 19 6 Th l m nt ed in sleeve be r g i l k nd in g ld dental all y I d um ea be u ed t f rm p n j n t o w th g rm m n the pro d t n f m nd t l d m pho ph de h s u m high temperature transistors and solar bat te i ndium a enide and ind um antim n de are u d l w temperature transi tors



Indium metal Indi m is eco e d f m a by p odu t of th zinc s lfide smelti g proce s An a d l ch is f ll wed by h mi al sepa ations from multit de of oth r elements su h as zinc cadmi m ir n ar n c ant m ny nd al uminum Th f n l p r fic tio 99 9 p rity is u ually ac ompl hed by queous lectr lys Ind um a ft m tal wh ch an be e sily c atched with the fi e na l It ha the inte est ng prop rty of adher ng t the s rfaces wh n rubbed a r s them It ha a melt ng point f 156 4 C, a boiling poi t g eater th a 2000 C and a den ity of 7 31 g/cm at 20 C. It cry t lliz i th f e-c ntered tetrag n l truct re The stand rd oxid t on pot ntial fo the act n

$$I \rightarrow In + 3$$

is +0 34 v lt The met l di l es n all cids t g e soluti n f tl idat on tate III The t of xid t n of ind um metal by oxygen f the a r i ery low up to the melting p o nt b t at high temperatu es t rap dly y ld the yell w x de I O I di m r a t d ectly w th the h l gens when w m

Indium compounds Ele t d ff a t on studies sh w th t the hl ride br mide nd iod de a e all dim ric the p r st t The anhyd u fluoride nly ry sl ghtly s lubl n water whe e s the the t hal d ery oluble Although the t i iod d s p l y ll w in olo the th r tr hal d are col rle s The trihalide hyd ates ar r c v red f m the aqueou ol tion

In q eo s luti n th ly stable oxidatio state of nd m i III A 0 1 M I t on of ind um t ihal des hyd ly s t g e a pH of abo t 3 Upo the dd ti n of b e u ha ol ti n th h drated xid p p tate at pH of about 3 4 Indium hyd o de s not amph t r d e the t ale t o fo m a st ble compl x w th mmoni The car bon t o l t d s lfide n ol ble wat

Comp u ds f th mpo t InX e pt f the d d h e bee p ep ed The fluorid p e p ed by pa t l ed ct f the t fl o de w th hydr ge a d th hl d nd br m de by a t f hyd g n hydroge h l d m t r on the c rrespond g t h l de Th hlo ide nd b om d

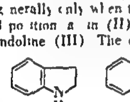
both melt at 235 C The e compound are diamagnetic and thus may be $In^{I}(In^{III}X_4)$ compounds Reduction of the trichloride and bromide with indium metal result in product of composition InX When added to water the reduced state compounds disproportionate to the metal and the oxidation state III

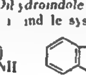
Indium forms *organometallic compound* mainly of the R_3In class where R is either alkyl or aryl The reaction of indium metal with mercury alkyls (aryls) give the desired products Indium organometallic compound tend to be associated in solution and are easily oxidized in the air

Indium may be determined quantitatively with 8 hydroxyquinoline by precipitation of the compound $In(C_9H_6ON)_3$ at 70–80 C from a sodium acetate–acetic acid buffer followed by drying at 120 C and direct weighing of the precipitate An alternate to the direct weighing is the bromometric titration procedure after solution of the compound *in warm 10–15% hydrochloric acid or the colorimetric* determination at 400 mμ of a chloroform solution of the 8 hydroxyquinolate *See* GALLIUM THALLIUM [F M L]

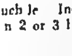
Indole

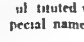
One of a group of organic heterocyclic compounds in which a benzene ring is fused to a pyrrole ring Indole (I) is a typical member of the group (see

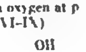

(I)


(II)

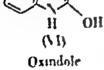
HETEROCYCLIC COMPOUNDS PYRROLE) Indolenines refer to isomeric systems which are of interest generally only when two groups are present at the 3 position as in (II) *2 3 Dihydroindole is called* indoline (III) The dihydroisoindole system (V)

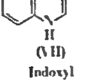

(III)

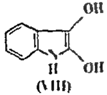

(IV)

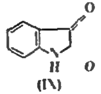

(V)

has received some study the isoindole system (IV) much less Indoles substituted with oxygen at positions 2 or 3 have special names (VI–IX)

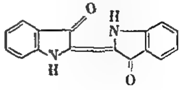

(VI)
Oxindole

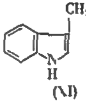

(VII)
Indoxyl

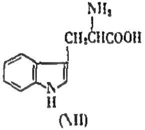

(VIII)
Dioxindole


(IX)
Isatin

The indole skeleton occurs in many natural products Examples might include the blue dye indigo (X) the plant growth hormone heteroauxin (XI) the amino acid tryptophan (XII) and the indole alkaloids for example strychnine Trypto-


(X)

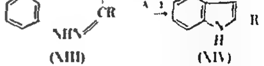

(XI)


(XII)

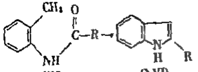
phan not only is one of the essential amino acids for man but also is the biochemical precursor of the indole plant alkaloids it is also very likely the progenitor of indole and 3 methylindole (skatole) which are produced by pyrolysis or putrefaction of protein material

Properties and preparation Indole (I) is a steam volatile colorless solid mp 52.5 bp 253 C. It is found in small amounts in coal tar in feces and in flower oils Indole is not ordinarily classed as acidic or basic although it is an active hydrogen compound in which hydrogen at the 1 position is replaceable by metal In the absence of oxygen indole is stable to heat and to alkali Indoles are sensitive to acids and to oxidation processes however the more highly substituted indoles are in general more stable Indole can be regarded as a relatively reactive aromatic compound Electrophilic substitution favors the 3 position and to a lesser extent the 2 position The experimental resonance energy for indole is 54 kcal mole

Indole syntheses proceed by fusing a five membered N heterocycle on a benzenoid compound Of the many known syntheses the Fischer indole synthesis is the most versatile By this method a phenylhydrazone (XIII) of an aldehyde or ketone on treatment with acid is converted to an indole

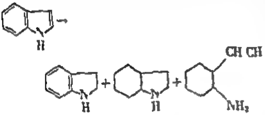

(XIII) (XIV)

(XIV) For example when the starting material is the phenylhydrazone of acetone the product is 2 methylindole The R groups at positions 2 and 3 may be varied widely Substituted indoles are formed when the phenylhydrazone (XIII) is substituted on the benzene ring Another synthesis is cyclization of [illegible] derivatives (XV) to indoles (XVI) by heating them in the presence of strongly basic reagents



(XV) (XVI)

I d l s r atta ked at the 2 3 b nd by r z ne per x des and ther reag ts Catalyt hy d gen t y eld n t nly indoli (III) but l d pe d ng o n dit n octahyd oi dole (XVII) nd o ethyley l l xylam n (XVIII)



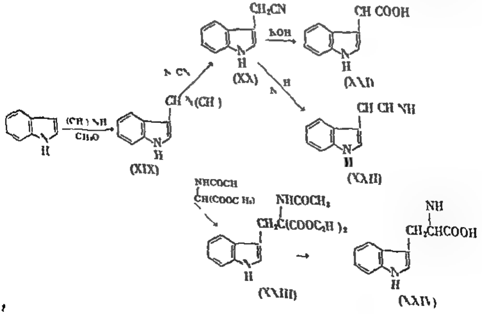
(XVII) (XVIII)

I dol ub t tut t the 3 p t n ometime t the 2 p ti n but only ra ely th ben n g Gr p i serted by ub t tut on n l de chl o odo n t o n tr l az Ind le 3-car bo ald hydes e f rmed n th re ct with hl f m nd lk l (R mer Tiema n) r with N methylf rm n l d a d ph ph s yehl de Th l od de t of dol re t with methyl od de to gi e m nly l m thylind le I d les with ethylmagnesi m od l gi e l nd l l m gnes m od d wl l c mb with lkyl h lid yl h l d b di x de ethyl chl o- bo t f rm ld hyde and ethyl o th form t t g espect ly 3- lkyl ndoles 3- cyl nd l d l 3-ca bo yl ac d the corre po di e t 3-hyd ymethyl nd l nd dole 3- box ld hyd s.

Important derivatives Gramine r 3-d methyl ami omethyli dole (XIX) i one f the impl e t nd le alkal d G amin i prep red by condensa t of indole d methylamine and fo maldehyde The dimethylam no grouping either a such or aft r qu tern zat on an be d pla ed moothly by nu le philic gr up Thi property has been ex ploit d fo the sy thes s f va i u 3- ub tituted i d le For exampl the re cti n f gramine with od um cy nide g es 3-cya omethyl nd le (XX) wh ch is hyd olyzed by alk l t gi e het roau i (XXI) r whicl redu ed by hyd ogen and Ran y nickel c taly t to trypt mine (XXII) Gra mi e w th ac t m d mal nic este give the inter mediate (XXIII) wh ch can be converted to tryptophan (XXIV)

S r t in or 5-hyd ytryptami e (XXV) an ff cti e lo al vas co tr ct d stributed th ugh ut the body Buf teni e (XXVI) fo nd in the sk n of tl commo t ad i a act e pre r g nt Both ser t in nd bufote i ha been ynthe ed 5 6-D hydroxy nd le derived in vivo l y the biochem cal id t on a d d carboxyl tion of tyros ne gi s ri e by furthe x dat on to the da k k n pigme t mel n Th ind l e e e ne r phy tigm e (XXVII) s a pecific nhib tor t th act n of ac tyl l l e t ra nd a u h is eff cti n block g ery cond ct on Gl tox n (XXVIII) a f ngus der ed antib t

Ind g dye h s be n k wn for e tu ie Ind o r d oti (XXXI) a d its der ati es in lud g the thi nd g in wh h S tak s the place of NH are mme c ally mp tant dyes I d ca (XXIX) a glu os de of indoxyl is f und in ar u pec e *I l d g f ra* Natu al nd go i obta ned by zym t c hyd olysis f nd an f ll wed by ai -ox dat n of the es lt ng ind xyl (XXX) *Although* ma y synthe es ar known th impor t t c mmer i l ynthe e a losely related t th t how in the a c mp nyi g form lat ns in



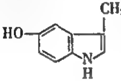
which phenylglycine (XXXII) is an intermediate. Substituted indigos are prepared from indigo or by total synthesis. The bromo and chloro derivatives are valuable dyes. Tyrian purple, or 6,6'-dibromoindigo, is a dye of antiquity obtained from a Mediterranean snail.

3-Hydroxyindole, or indoxyl, is a yellow compound with an unpleasant odor. It is easily oxidized with air or with ferric chloride to indigo. Reduction with sodium amalgam or with hot zinc dust affords indole. The reactive 2 position of indoxyl combines readily with aldehydes to give colored indogenides such as (XXXIV) and with nitrous acid to give isatin α-monooxime (XXXIII).

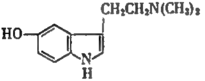
Oxindole is 2-hydroxindole; however, the tautomeric amide structure (XXXVI) is probably the more appropriate formulation. Oxindole can be prepared by Friedel-Crafts cyclization of N-(chloroacetyl)aniline (XXXV) or by a two-stage reduction of isatin. The oxindole 3 position may be alkylated, nitrosated, acylated, or condensed with aldehydes.

Dioxindole (XXXVII) is produced by hydrosulfite reduction of isatin (XL) or by cyclization of o-aminomandelic acid (XXXVIII). Oxidation of dioxindole regenerates isatin; reduction gives oxindole (XXXVI).

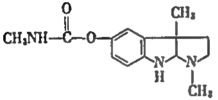
Isatin, or 2,3-dioxoindoline (XL), is prepared by oxidation of oxindole, by oxidative cleavage of indigo, or by ring synthesis. One standard isatin synthesis (Sandmeyer) proceeds by cyclization of isonitrosoacetanilide (XXXIX), which is obtained from aniline and chloral oxime. Isatin is a red, weakly acidic material. The reactive carbonyl group at the 3 position takes part in familiar car-



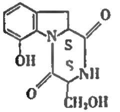
(XXV)



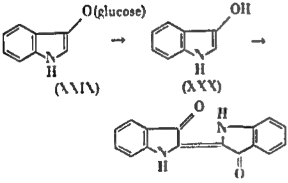
(XXVI)



(XXVII)

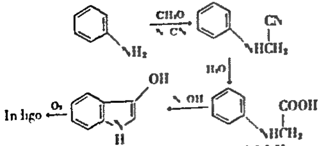


(XXVIII)

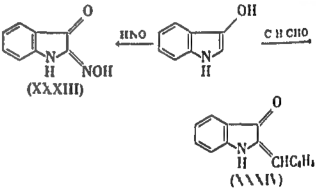


(XXIX) (XXX)

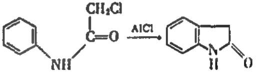
(XXXI)



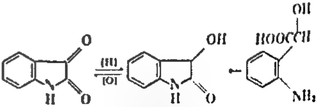
(XXXII)



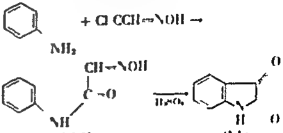
(XXXIII) (XXXIV)



(XXXV) (XXXVI)

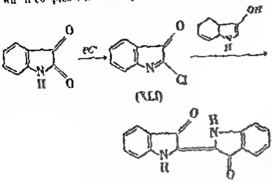


(XL) (XXXVII) (XXXVIII)



(XXXIX) (XL)

bo yl dd t n reacti s Ph ph u p ntachlo-ride c nverts ati to i atin α bl r de (XLI) wh h co ples with ndoxyl in a tandard and u



(XLI)

t l i d g ynthes I atin an be c n ert d the Pfit ge p o es t quinol e deri ati e S e Qui oline [W J CE.]

Bibliography R. C. Elderfield (ed) *H t cy l c Comp ds* v 1 3 1952 W C. Sumpt d F M M lle *Het rocyclic C mp ds u th Ind l and C ba ole Sy tem* 1954

Inductance

That pr pe ty of an electr c ir it r of two neigh bori g i u t whereby n el ctr m t ve f c d c d (by th proce f el ctrom gnet c ndu t n) of the i u ts by a cha ge f curr nt i th f them S e Electromotive force (emf) Induction electro s c ftic Th te m i d t n f s metim ed a a syn nym f r du t a d p e g the p operty of d t (e Inductor)

Self inductance F r g e oil the rat o of th lectr m ti fo ce of i d ct o t the rat of ha ge f rr t the o l i call d the elf ndu t L i the)

$$L = -\frac{e}{dI/dt}$$

wh e th l t m is f e t y n t nt d dI dt th r te of ha g f the urre t t th t t nt The n g t ign di te that the d ed f ct om t f t opp it i d e t t th e nt h th t n rea ing (dI dt po t e) a d th same d ect o as th t wh the u e t t d c e g (dI dt n gat e) The s lf ndu t n t h tya wh th l t m ti f e n olt d il t f h ng f r t n amp n pe sec nd S Henry

A aft at d fi t f elf nd t n s th mber f fl x l k ges p r unit nt Fl x l nk g th p od t f th fl x a d the umb r f tu n th l Th

$$L = \frac{N\Phi}{I}$$

M lt pl both des f th q at o by I t bt i

$$LI = N\Phi$$

and d fferentiate with r spe t to t

$$L\frac{dI}{dt} = N\frac{d\Phi}{dt} = -e$$

or

$$L = -\frac{e}{dI/dt}$$

Henc th ec nd definitio eq alent t th first

S lf ind ctan e do s not affe t a c r uit in which the curr nt i un ha ging but it i f gr at impor tan e wh ther s a ch nging current inc there i an indu ed emf du ing the tim that the change takes pla e F r xample in n alternating u r nt ci cuit th urr nt s c n t ntly hanging a d the nductance is an important fact r Al in tran si t ph n m n at the beg nning or end f a teady unid r ctio al current th elf nductance plays part *See* Tran ient electric.

Con id r a ir it of res tan e R and inductance L onnected in ser e to a on tant urce of po-tent al diff en V The cur ent in the c rcuit d s not rea h a fi al teady al e in tantly but ri es t wa d the final alue I = V/R in a man n that d p nd pon R a d L At e ery in t nt after th wit h s clo ed th applied pot nt al diffe ence th sum of th iR d p i p tential and the ba k mf L di/dt o

$$V = iR + L\frac{di}{dt}$$

whe e is th in tant eous value of the c rre t Sep r t ng the i ble i nd t o e obta ns

$$\frac{di}{\frac{V}{R} - i} = \frac{R}{L}dt$$

Th olut on of this q at on

$$i = \frac{V}{R}(1 - e^{-(R/L)t})$$

The curr nt r es e p nt ally t fi al te dy lu V/R The rate f gr wth ap d at fi st the le s a d le s p d a th urrent appr ches the fi l al e

The p we uppl ed t th circ t at ve y in ta t duri g the r f curr nt is gi en by

$$p = Vi = i^2R + L\,i\,di/dt$$

Th fi st term i^2R is th p er th t goes into he t ing the c t The e nd term L di/dt s the powe th t g es t b ild g up th m gn t feld in th nduct The total e gy th t ed n b ld g p th magnet c fi ld i

$$W = \int_0 p\,dt = \int_0 Li\frac{di}{dt}dt = \int_0^I Li\,di = \frac{1}{2}LI^2$$

Th ene gy th t h bee d in bu ld ng up the magn t fi ld rema as e e gy f the m g etic field Wh n th e tch i op n d th mag et fi ld ll p es a d th nergy of th field s returned t th ci cuit, re lt ng n an ind e d emf The are

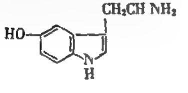
which phenylglycine (XXXII) is an intermediate. Substituted indigos are prepared from indigo or by total synthesis. The bromo and chloro derivatives are valuable dyes. Tyrian purple or 6,6'-dibromoindigo is a dye of antiquity obtained from a Mediterranean snail.

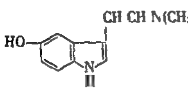
3-Hydroxyindole or indoxyl is a yellow compound with an unpleasant odor. It is easily oxidized with air or with ferric chloride to indigo. *Reduction with sodium amalgam or with hot zinc* dust affords indole. The reactive 2 position of indoxyl combines readily with aldehydes to give colored indogenides such as (XXXIV) and with nitrous acid to give isatin α-monooxime (XXXIII).

Oxindole is 2-hydroxindole; however, the tautomeric amide structure (XXXVI) is probably the more appropriate formulation. Oxindole can be prepared by Friedel-Crafts cyclization of N-(chloroacetyl)aniline (XXXV) or by a two-stage reduction of isatin. The oxindole 3 position may be alkylated, nitrosated, acylated, or condensed with aldehydes.

Dioxindole (XXXVII) is produced by hydrosulfite reduction of isatin (XL) or by cyclization of *o*-aminomandelic acid (XXXVIII). Oxidation of dioxindole regenerates isatin; reduction gives oxindole (XXXVI).

Isatin or 2,3-dioxoindoline (XL) is prepared by oxidation of oxindole, by oxidative cleavage of indigo, or by ring synthesis. One standard isatin synthesis (Sandmeyer) proceeds by cyclization of isonitrosoacetanilide (XXXIX), which is obtained from aniline and chloral oxime. Isatin is a red, weakly acidic material. The reactive carbonyl group at the 3 position takes part in familiar car-


(XXV)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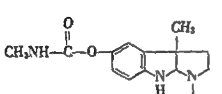
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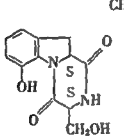
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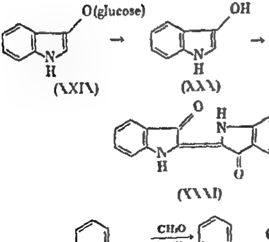
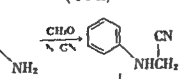

(XXIX) (XXX)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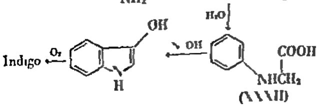
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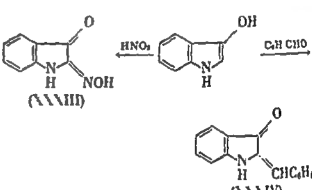
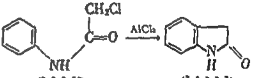
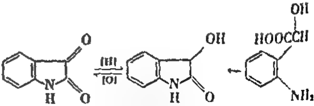
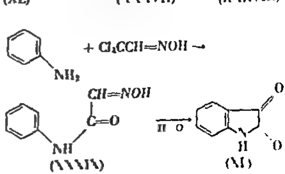
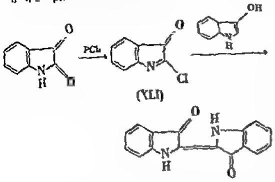

(XXXIII) (XXXIV)


(XXXV) (XXXVI)


(XL) (XXXVII) (XXXVIII)


(XXXIX) (XL)

bonyl addu react n Pho ph r pentachlo- de con erts at n to sat -α-chl ride (XLI) b h e ples with doxyl in a st nda d and e-



(XLI)

ful ind g ynth I atin be con rted n the Pfitz ger process t qu n l n de v t e *Se* QUINOLINE [W J GL.]

B bl g aphy R C. Elderfi ld (ed) *Hete ocy l c Compou ds* 1 3 1952 W C Sumpt r and F M M lle *H te ocy li C mp d with I dole nd C b l Syst ms* 1954

Inductance

That p ope ty of an el ct c r u t f r w neigh bo g c r t wh reby a el t omoti fo e i i d ed (by th p es of electromagn ti i duc t n) n of the ci u t by a h nge f current i th of th m S ELECTROMOTIVE FORCE (EMF) I DUCTION L CT O IA ETI The term ind cta c e il s m tim us d a ynonym f d t a de ic po i g th pr p rty f du t (INDUCTOR)

Self inductance Fo a g en co l th r t i th I tr m t e f e f i duct on t th ate f ha g of m t i tl l all d th s lf d t n *L* of th c L

$$L = -\frac{e}{dI/dt}$$

h th lect mot e I c t any in t nt nd dI/dt th rat of cha g f the rrent at *th t* t t Th n g ti gn i d cates th t th ndu ed lectr m t for e opp te n di ec t n t th nt when the c r ent c a ng (dI/dt po t ve) and n th s m d ect n the *nt* h n ch u t s d re ng (dI/dt g ti) Th ll ndu t i henry wh n th lect m t f c lt d the at f h f urr t amperes per se d S He r

A lt t d fi to f ll d cta c i th mbe i fl x l k es per u t re t Fl x l k g th p od t of the fl and th n mber f t n th l Th n

$$L = \frac{N\Phi}{I}$$

Mult pl b th d f th q t n by I to btai

$$LI = N\Phi$$

and diffe ent at with r pe t to t

$$L\frac{dI}{dt} = N\frac{d\Phi}{dt} = -e$$

r

$$I = -\frac{}{dI/dt}$$

Hen e the c d d fin t n i equi alent t the fi t

Self d ctance doe not affe t a c r it in wh ch the urre t i n h n ing but it i of great mpo t n e when the e i a changing current s n e there is an nd ced emf d r ng th time that the change t kes pl ce F r example in an alternati g c i rent c rc it the urrent i c nsta tly hang ng and the i duct n i an mport nt f cto Al n tran s e t phen m n at the beg nning end f a t ady u d c tional cu rent th elf ndu tan e pl y a part. *S e* TRANSIE T ELECTRIC

Co s der a c t of e ta ce *R* and inductan e *L* onn cte l in se ies to a con ta t ou ce of po- tential diff re *E* The c r ent in the c rcuit d n t e ch a final teady alue i tantly but ri es toward the fi l alue $I = E/R$ i a manne that depe ds upon R a d L At ry in ta t afte the switch is cl ed th appl ed pot tial d ffer nce is th um f the *iR* drop in pote t l and the back emf $L\,di/dt$ or

$$E = R + L\frac{d}{dt}$$

wh re *i* s the stanta eou alue of the cu rent. Separ ti g the v table t and *i* one obtai s

$$\frac{d}{\frac{E}{R} - i} \quad \frac{R}{L}\,dt$$

Th ol ti n of this q ation

$$i = \frac{E}{R}(1 - {}^{-(R/L)t})$$

Th c rent r es exp nentially t a fin l teady alue E/R The rate f g wth i apid at fir t then le and l s p d the rrent appro he the fin l l e

The powe uppl d to the ci c t at ev y n t nt du i g th r e f c r e t gi en by

$$p = iE = R + I\ d/dt$$

The first t rm ^{2}R is the p we that g t f eat the c t The e nd term $L\ d/dt$ is th powe th t g s to b ild g up the m gnet c fi ld i the *nducto* Th total n rgy that i u ed i b ildi g p th magnetic field s

$$W = \int_0 p\,dt = \int_0 Li\frac{d}{dt}dt = \int^{I} Li\,d = \tfrac{1}{2}LI^2$$

Th s ne gy th t ha been u ed i b ild ng p the m gn t c fi ld r ma s a ene gy of the m gnet c fi ld Wh n the sw tch op d the m g et c field ollap es d th nergy of *th* ld i ret ned to the cu t re h ng n an indu ed *emf* The a

that is often seen when a switch is opened is a result of this emf and the energy to maintain the arc is supplied by the decreasing magnetic field

Mutual inductance The mutual inductance M of two neighboring circuits A and B is defined as the ratio of the emf induced in one circuit to the rate of change of current in the other circuit

$$M = -\frac{\mathcal{E}_B}{(dI/dt)_A}$$

The mks unit of mutual inductance is the henry the same as the unit of self inductance The same value is obtained for a pair of coils regardless of which coil is taken as the starting point

The mutual inductance of two circuits may also be expressed as the ratio of the flux linkages produced in circuit B by the current in circuit A to the current in circuit A If Φ_{BA} is the flux threading B as a result of the current in circuit A

$$\mathcal{E}_B = -N_B\frac{d\Phi_{BA}}{dt} = -M\frac{dI_A}{dt}$$

or $$N_B\, d\Phi_{BA} = M\, dI_A$$

Integration leads to the result

$$M = \frac{N_B\Phi_{BA}}{I_A}$$

See INDUCTANCE MEASUREMENT [K V M]

Bibliography *See* INDUCTION ELECTROMAGNETIC

Inductance bridge

A device that compares inductances The inductance bridge is a special case of an impedance bridge Just as the Wheatstone bridge is used to compare resistances the impedance bridge is used

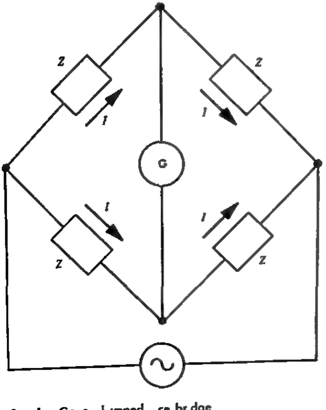


Fig 1 General impedance bridge

to compare impedances which may contain inductance capacitance and resistance

General impedance bridge A general impedance bridge is shown in Fig 1 Four impedances Z Z_b Z and Z_d are connected into a square array A source of voltage v is applied across one diagonal of the square and a detector or galvanometer G is connected across the other diagonal The bridge is balanced when the current through the galvanometer and hence the voltage across it are equal to zero

If the voltage across G is equal to zero the instantaneous voltage drop across Z_b must equal that across Z_d If the instantaneous sine-wave voltages are equal they are equal in magnitude and are in phase with one another Equating the magnitudes $Z I = Z I$ and following the same reasoning $Z_bI = Z_dI$ The current in Z_b is equal to the current in Z because the current in G is equal to zero Similarly the current in Z_d is equal to the current in Z Eliminating I and I from these equations an equation of balance is obtained

$$Z\, Z_d = Z_bZ$$

The voltage across Z leads I by the power factor angle ϕ and the voltage across Z leads I by the power factor angle ϕ If I leads I by the angle ϕ then $\phi + \phi$ must equal ϕ if the two voltage drops are to be in phase Similarly $\phi + \phi_b = \phi_d$ Eliminating ϕ from these two equations the second equation of balance for the impedance bridge is obtained

$$\phi + \phi_d = \phi_b + \phi$$

Several important properties can be recognized by considering the second equation of balance If Z and Z_b are resistors with ϕ and ϕ_b both equal to zero then for balance $\phi_d = \phi$ This means that Z and Z_d must both be inductive or both capacitive for balance If ϕ and ϕ_d are both equal to zero the second equation for balance becomes $\phi_b + \phi = 0$ This means that Z_b is inductive and Z is capacitive or vice versa

General inductance bridge The inductance bridge of Fig 2 has resistors R and R_b as ratio arms and compares an unknown Z with a standard consisting of R_d and L_d If the standard L_d is variable it and R_d are varied to reduce the detector voltage to zero This balances the bridge and the equations of balance become

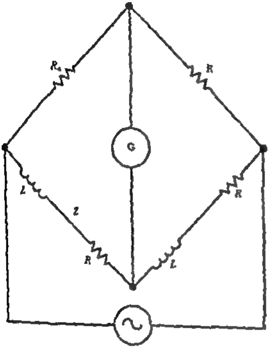
$$L/L_d = R/R_d = R/R_b$$

Sometimes a substitution method is preferred In this case the balance is obtained as above with any good quality inductance for L_d The unknown is then replaced by a standard L in series with R The bridge is balanced a second time by varying L and R When balance is obtained L equals L and R equals R_d For inductance standard *see* INDUCTOMETER

If the standard is not adjustable it becomes necessary to vary one of the ratio arms R or R or both as well as R_d in order to obtain balance

Ob ı u ly the b t tutı method ann t be p- pl ed wher nly fixed tand rds ar \ a l l le

Theoret ally the d tı n for l lance ıs nde- pende t l f eque cy In p act e the c pa ıtan e betwe n t rn and b t een layer of w r ın the two c ıl w ll be d ffe ent d t high f eq n e th bridg can b bala ced at nl one frequ ncy at a tım Under ch ondıt n harm n c n the upply v lt ge w ll m ke ab olute balance mpos-



Fg 2 G l d ct e b dg

ble When harm nı s are pre ent the br dg h ll be balanced by redu c ng the fundam ntal mpo t ın the detector oltage to zero Thı cond tı n doe n t ne e arıly co re p nd to m nı mum dete to oltaı e A te hnıcıan can s m t mes achı a bala e by ear at audı fr quen ı An o-cillo c pe pr des a better mean f eeı g when the fu dament l l as been educed to zero

Anderson bridge Thı b ıdge hown ın Fig 3 c n b u ed to mea ure the ductance L ın term of a t ndar l cap cıtance C Mo t lab ra t rıe hı n tock m re a ı bl capacitor th n ı d ctometers A mea urement lepend ng upon ındu t mete s s more likely to be delayed th n a me ur m nt depe d ng up n apacıtance be- ca s the app p ate ınd ctomete ı n t ava l able The equ t o s of balance of th s br dge are

$$L_b = \left(R_d + \quad + \frac{R_d}{R_s}\right) R_s C$$

$$R_b + r_b = \frac{R_s R_d}{R_s}$$

The b dge ıs u u lly balanc d by varying r and C The ec nd equat on ndıcat that i r ome ch ıce of R R nd R n gat e r might be requ r d Con quently ıf a balan e does *not* e m p ble by arying C and r_b R or R hould b ncre ed or R should be ed c d Th wıll ın cre e $R R_d/R$ wh h ı need d be au e bal a ann t be btaı ed unless th s q antıty ı at l a t as la ge s R

Carey Foster bridge Thı eful brıd f r de- t rmın g m t l ı ducta c ı h wn n Fig 4 Th brıd ı th et ally ı d pende t of fre- qu cy Wh n the bridge ı balan ed

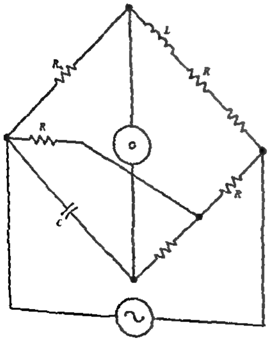


Fig 3 And so b ıdg

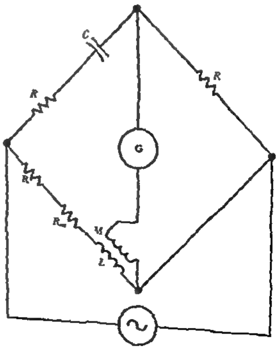


Fig 4 Ca y F te b dg

$$M = R\ (R_M + R)C$$
$$L = (R\ + R\ )(R_M + R)C$$

If these equations are to be used directly the resistance R_M of the coil must be measured by some other circuit arrangement If a known large resistance R is connected in series with the coil it may be possible to neglect R_M in comparison with R and the equations become

$$M = R\ RC$$
$$L = (R\ + R\ )RC$$

Resistances R and R are varied to obtain balance An obvious advantage of this bridge is that all balancing operations can be performed by varying resistances The capacitance C may be a constant standard

Any discussion of impedance bridge operation should include mention of Wagner ground precautions Each portion of a bridge has a capacitance to ground as well as to all other portions In the case of high impedance circuits and at high frequencies the e capacitances are not negligible A Wagner ground consi ts essentially of two bridge arms placed across the ource with the common point grounded The Wagner ground is balanced to bring the detector terminals to ground potential When this is accomplished the stray capacitances no longer affect the balance or give spurious unbalance signals in the detector *See* IMPEDANCE MEASUREMENTS HIGH FREQUENCY INDUCTANCE MEASUREMENT [H SO]

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Inductance measurement

The determination of an electromagnetic parameter of an electric circuit The electric current in a circuit produces a magnetic field which is considered to consist of lines of magnetic flux that link the circuit Whenever the magnetic field linking a circuit changes a voltage is induced in the circuit The faster the change in the field the larger is the induced voltage When there is no ferromagnetic material pre ent the magnetic field is proportional to the current i and the induced voltage v is proportional to the rate of change of current

$$v = L\ di/dt$$

The proportionality factor L is by definition the elf inductance of the circuit If v is measured in volts and if the rate of change of current is in amperes per econd the inductance has the dimensions of henries

The direction of the induced oltage is pecified by Lenz s law which states that the current that would be produced by the induced oltage would be in a direction that oppo es the change in the magnetic field Hence the inductance of a circuit represents the tendency of the circuit to resi t a change in current Thi is analogous to the manner in which the mass of an object tends to resi t a change in its velocity *See* INDUCTANCE LENZ S LAW

If the magnetic field produced by the current in one circuit links with another circuit the relation between the voltage and the rate of change of current still holds The proportionality factor in this case is called the mutual inductance *See* COUPLED CIRCUITS

If ferromagnetic material is pre ent saturation and hysteresis effects may be evident for ome values of current For such cases everal definitions may be introduced or the concept may be discarded entirely An effective inductance is defined as the ratio of the effective induced voltage to the effective rate of change of current and is a function of the maximum current When the current changes about a certain average value and the magnitude of the change is mall compared to the average value the above definition pecifies an incremental inductance This inductance is a function of both the average current and the magnitude of the change

Inductance standards Coils con tructed so that their dimensions and consequently their inductance remain constant over long periods of time are u ed as inductance standards If the dimen ions are known the inductance can be computed from the formula

$$L = N\ P$$

where N is the number of turns of wire compri ing the inductor and P is a proportionality coefficient Such an inductance is called a primary standard (*see* INDUCTOMETER) Standards are u ually maintained at constant temperature to keep the coil size and therefore the inductance from changing in value

When the inductance cannot be computed precisely it may be measured by comparing it with a primary tandard and it would then be called a secondary standard

The effect of inductan e is manife ted only when the current in a circuit i changing with time Any means of measuring inductance mu t employ changing current Usually the current i an alternating current of frequency f given by

$$i = I_m\ \ \sin 2\pi ft$$

with a maximum in tantane us value of I_m The voltage induced by the hanging mag etic field i

$$v\ = 2\pi fLI_m \cos 2\pi ft = V\ \ \cos 2\pi ft$$

where L is the self inductance in henrie The ratio of V to I_m is c lled the reactan e f the ircuit and i repre ented by X in

$$X = 2\pi fL\ = V\ \ /I_m$$

Impedance measurement Th is th det rmi nati n of the t tal eff ct of a r uit element Every in luctance i wound with wire that ha re i tance Th is mean th at very indu tan ha re i tance and c n er ely it i al tru th at ry

res t r has induct nce G nerally mea urement t d t rmin the r d ctance of a c rc t t actually an mpedance mea r ment d g ves the re i t ance as well the r du tance See INDUCTANCE BRIDGE.

If the c cu t has r s t n R the total oltage d p t g n by the formula

$$v = RI_m \sin 2\pi ft + XI_m \cos 2\pi ft$$
$$= ZI_m \sin (2\pi ft + \phi)$$

wh r $Z = \sqrt{R + X}$ is th mpedanc f th cu c t a d ϕ s the phase a gle the p w r fac tor a gl f the c cuit g en by the el t on is $\phi = X/R$

It mposs bl to con t ct an nducto with an hm c res t nc f z ro h we e by ca ef l de g it i po bl t minim e th resi tance for a g e am t f duct n e Th fa to of m rit f any ndu to s called the Q f th ndu t nd d fined as the rat f the r ctan to th effec t e resi t nc at y spec fied perating frequency

$$Q = \frac{\pi fL}{R_f}$$

Th effecti esi tan e R_{ef} rep es nt the c m b ed re sta e f th w r pl ddy-cu r nt l in the w r t the p cified per ting f e q cy The Q of a well-d gned r d o-f eque cy i d t r w ll be on th o d r f sever l hu d ed S Q FACTOR

If the Q f t duct i high en gh that th ffect e resi tanc may be n gl cted th n t ght f rward ppl cati f Ohm law perm t mea u ng the ind ct n e d

$$L = \frac{1}{\pi fI}$$

M a me t of d tr b ted nd t n e of able l a d wa gu d i a mpl shed nd r tly F r y l w fr qu n es th c ble urr nts r d t b ted n t rml thr gh ut the onduct nd th ndu t u t l gth max m m At h ghe f q n es th skin effect ca e th rr nt c e trat al g th nd t r u fa Th n ent at d e t affect the m gnet c fi ld bet een th co d ct but t d es t nd to l m t th fi ld w th n a h ndu t it If Th edu t i m gn t field b gs bout ed ct n i d t Con q e tly a the f e q y n a ed th i d ct nc d e se p ll a h g fi ed al

Th pa t n u unt l gth f able r pe w r t m n l n t d pendent of fre q nd be m a red at low f quen ies If d ect m m nt of tten t on nd veloc ty of p p g t r m d th nd t nce pe u t length l t m l m y b mputed t any f l of pe ti S ELECTRIC L MEASURE

[H O]

B bl g phy F A Law *El trical M m t* ed 1938 M B St t *B c El tri al M a m* 1950

Induction electromagnetic

Th p oducti n of an electromot e f ce either by mot on of a nductor through a magnetic field in such a ma n r as to cut acr ss the magnetic flux or by ch nge in the magneti flux that thread a conductor *See* MAGNETIC FLUX

Motional electromotive force A charge m v g pe pendi ula to a m gn t c field exper ences a fo ce th t i perpend cular t both the d ection of the field and the di ection of motion of th charg In ny metallic conductor there are f ee el ctron lectr ns that have been tempor rily detached fr m th par nt atoms

If a c ndu ting bar (Fig 1) m es th ough a magnetic field each free electron experiences a f ce due to its m t on thro gh the field If the di re tion of the moti n is h that a omponent of the f rce on the electr ns is par llel to the conduc to th lect ns will m ve al g the conduct r Th electron will mo e ntil the forces due to th m tion f the ond cto through the magnetic fi ld a e balanced by electrostat c f rc s that ri e be au e elect ons c lle t t one nd of the c nductor lea ing a defi t of lectron at the othe Th e is thus an elect i field along the rod and hence a po t ntial diffe ence b tween the e ds f th od while th mot n continues A so n a the m tion stops the electr tat c f r s will au e the lectrons to eturn to the r norm l d trib ition

From th defin t on of magn t c induct on (fl x dens ty) B th fo ce o a harg q due to th mo t n f the charg th o gh a magnetic field i g en by

$$F = Bqv \sin \theta$$

wh re the force F s at r ght angl s to a pla e de t rmined by the d ecti n f the fi ld and the *om po ent* $v \sin \theta$ f the elo ity is p rpendic la *to the fi ld* Wh n B s in webers/m q is in c u l mb and v s in mete s/ c the fo e s n n w t s S I DUCTION MAGNETIC

Th lect i f ld int ty E d e to th is forc s g en i magnit de and d re ti n by the fo c pe u t po t e ch ge The electr field nten ty i qual t th n g t of th potenti l g ad ent along th rod I moti al lect mot e f r

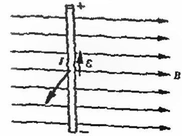


Fig F d ty B mot d d ed emf ℰ wh d ct of l gth l m f m fi ld (F m R L W b M W Whi d K V M g Phy t f S a d E g ee g McG w-H ll 1957)

(emf) the charge being considered is negative. Thus

$$E = \frac{F}{-q} = -Bv \sin \theta = -\frac{\mathcal{E}}{l}$$

or

$$\mathcal{E} = Blv \sin \theta$$

where l is the length of the conductor in a direction perpendicular to the field and $v \sin \theta$ is the component of the velocity that is perpendicular to the field. If B is in weber/m^2, l is in meters, and v is in meters/sec, the emf $\mathcal{E}$ is in volts.

This emf exists in the conductor as it moves through the field whether or not there is a closed circuit. A current would not be set up unless there were a closed circuit, and then only if the rest of the circuit does not move through the field in exactly the same manner as the rod. For example, if the rod slides along stationary tracks that are connected together, there will be a current in the closed circuit. However, if the two ends of the rod were connected by a wire that moved through the field with the rod, there would be an emf induced in the wire that would be equal to that in the rod and opposite in sense in the circuit. Therefore the net emf in the circuit would be zero, and there would be no current.

Emf due to change of flux When a coil is in a magnetic field, there will be a flux Φ threading the coil, the magnitude of which will depend upon the area of the coil and its orientation in the field. The flux is given by $\Phi = BA \cos \theta$, where A is the area of the coil and θ is the angle between the normal to the plane of the coil and the magnetic field. Whenever there is a change in the flux threading the coil, there will be an induced emf in the coil while the change is taking place. The change in flux may be caused by a change in the magnetic induction of the field or by a motion of the coil. The magnitude of the induced emf depends upon the number of turns of the coil N and upon the rate of change of flux (*see* FARADAY'S LAW OF INDUCTION):

$$\mathcal{E} = -N \frac{d\Phi}{dt}$$

The negative sign refers to the direction of the emf in the coil, that is, it is always in such a direction as to oppose the change that causes it, as required by Lenz' law (*see* LENZ'S LAW). If the change is an increase in flux, the emf would be in a direction to oppose the increase by causing a flux in a direction opposite to that of the increasing flux; if the flux is decreasing, the emf is in such a direction as to oppose the decrease, that is, to produce a flux that is in the same direction as the decreasing flux.

Consider the case of a flat coil of area A rotating with uniform angular velocity ω about an axis perpendicular to a uniform magnetic field of flux density B. For any position of the coil the flux threading the coil is $\Phi = BA \cos \theta = BA \cos \omega t$, where the zero of time is taken when θ is zero and the normal to the plane of the coil is parallel to the field. Then the emf induced as the coil rotates is given by

$$\mathcal{E} = -N \frac{d\Phi}{dt} = -NBA \frac{d(\cos \theta)}{dt} = NBA\omega \sin \omega t$$

The induced emf is sinusoidal, varying from zero when the plane of the coil is perpendicular to the field to a maximum value when the plane of the coil is parallel to the field.

Self induction If the flux threading a coil is produced by a current in the coil, any change in that current will cause a change in flux, and thus there will be an induced emf while the current is changing. This process is called self induction. The emf of self induction is proportional to the rate of change of current. The ratio of the emf of induction to the rate of change of current in the coil is called the self inductance of the coil.

Mutual induction The process by which an emf is induced in one circuit by a change of current in a neighboring circuit is called mutual induction. Flux produced by a current in a circuit A (Fig. 2) threads or links circuit B. When there is a change of current in circuit A, there is a change in the flux linking coil B, and an emf is induced in circuit B while the change is taking place. Transformers operate on the principle of mutual induction. *See* TRANSFORMER.

The mutual inductance of two circuits is defined as the ratio of the emf induced in one circuit B to the rate of change of current in the other circuit A. For a detailed discussion of self and mutual inductance *see* INDUCTANCE.

Coupling coefficient This refers to the fraction of the flux of one circuit that threads the second circuit. If two coils A and B having turns N_A and N_B respectively are so related that all the flux of either threads both coils, the respective self inductances are

$$L_A = \frac{N_A \Phi_A}{I_A} \quad \text{and} \quad L_B = \frac{N_B \Phi_B}{I_B}$$

and the mutual inductance of the pair is given by

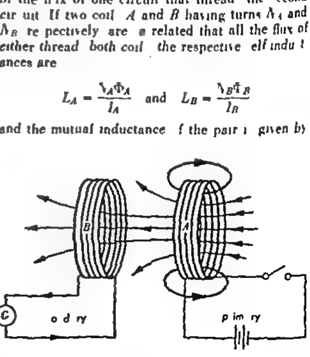


Fig. 2 Mutual induction. An emf is induced in the secondary when the current is changing in the primary. (R L Weber, M W White, K V M... Physics for Science and Engineering, McGraw-Hill, 1957)

$$M = \frac{\lambda \Phi_B}{I_B} = \frac{\lambda_B \Phi_A}{I}$$

Th $$M^2 = \frac{\lambda_A \lambda_B \Phi \Phi_B}{I I_B} = \frac{\lambda_A \Phi_A}{I_A} \frac{\lambda_B \Phi_B}{I_B} = L_A L_B$$

or $$M = \sqrt{L_A L_B}$$

In g r l n t all th fl x f om ne circuit th e l the sec nd The fr ti n f the flux f om ı t *A* that th e d ır u t *B* depends up n th d t n e b tw n the two c r u t th r o ı t ı n ith respect t h oth r and the pre n ≡ of ferr magn tic mate ıal n the neighborh od e the a a c re as a h eld It f llows th t fo the gen e al ca e

$$M \leqq \sqrt{L L}$$

The rat f the m t l ndu tan ≡ of the p ı to th quare oot f the pr d ct f the ndividual M nd ta alled the oeffic nt f c u pl g *k*

$$k = \frac{M}{\sqrt{L\ L_B}}$$

The upl g effic t h a m mum v lu f n ty if all the flux th ad both circu t z r f n ne f the flux f om o e ı u t th d the oth F r all th nd ti n K h a alu between 0 a d 1

Applications The phe m o of l ctromag n t c ı d ti n ha g t *many ımp* t appl t o n mod rn techn l F ample e COUPLED CI CUITS GE ERATOR ELECTRI I DUC TIO HEATI MI RO HO E MOTOR ELECTRIC STE IF HA I I [K V I]

B bl g ph S S Attwood *El tri and M g t F ld* 3d ed 1949 L P ge N I Adams *P ı pl f El t city d M g tism* 3d ed 19 9 F W Se *P cipl s of Phys cs* ol 2 19 1 R P W h *El tricity d M g eti m* 19 5

Induction electrostatic

A m thod h by lect ı al ≡ du t becomes lectr fied wi n h ged body It u f l es a se f m th f t th t f es ry lect b rge tl e som h n eq al a d pp t ı d d h g F d r l d d e ELECTROSTAT I S [R F W L]

Induction magnetic

A t q a ı ı th e s ed a a q a ttat m f m gn t c fi ld It def ed ı terms f th (e n a h rg m ı g n th fi ld f om th q ı

$$B = \frac{F}{qr\ \ \theta}$$

h ≡ th m gn t d of th m gn t du t l F i th f th h g q wh h m c g w th perd t ı d ect n mal ng a ≡ *θ* w th th d ect f th fi ld Th d t f

th ve t r q antity *B* is the dı ection in wh ch th for e on the m ı g charge ı zer

The magn t indu tion may al o be pr ed in terms of the fo ce *F* n a urrent element of length *l* and current *I* That ı

$$B = \frac{F}{Il \sin\theta}$$

The mks u it f magnet c ı ductio is der ed fr m thı q at on by e pres n the fo c ı newtons the current ın ampe es and th l gth ≡ meters Th u ıt f *B* s thus the newto /ampere meter

Magnet ≡ flu den ity is the m gnetic flux per un t a a thro h a urface perpend c lar to the magnet c nduction M gnetic flux den ity and m g eti ndu ti n a e two t rm that are equivalent S e MAGNETIC FIELD MAGNETIC FLUX

The magn ti indu tion may be r p e ented by l n s that a e d awn s that at e ery p nt ı th f ld th t nge t t the li e ı ı th d rect on of the m gnetic ind ti n T repre ≡ t the magnetic induction qualitati ly as many s ch line may be d awn a are eces a y to p rt ay th ≡ ≡ If how ever th l nes r to rep ent th magneti ı d c t *on qu nt t ti* ly an a bitrary choice mu t be made f r the number of li es to repre ent a g ven c nd tio O e uch ho ce ı that in which the num b r of lin per squa e m ter of urfa e j e pen dic l r to *B* et eq al ı th v l *e of B* These l n s are called m n t c fl x O l ne f ı du tio as her s lected ıs call d a flux of l webe The orrespond g un t of flux den ity is then the w ber pe q are meter Fr m th m *nne of defining* fl x ed he e t f llows that the web r p r qua e me ter ı quiv le t to th newto /amp e-m ter

An th r u it of flux den ity ıs d fi ed by usı g nt met r g am ≡ d (cgs) ıts both th de fi ng eq tat n f r magn ti nducti n and in the a which th re s un t fl x Th s cg n t of flux d n ity ı c lled the gau The rel t o th p between the gau s and the weber s gı en by 1 weber/m = 10 ga es Se GAU S

F r d us n of an *mf rtant* dev ce kn wn a b tatr whi h ut l ze the princ pl l ma net c ind ct n PARTICLE ACCELERATOR [K M]

B bl g phy E P P ck *El ct city and M g n tism* 19 3 F W S a s *P cipl f Physic* ol 2 1951

Induction coil

A d ı e fo pr du n h gh ltag ltern t ng urr t high olt g p ls fr m a l w oltage d re t c r nt Th la g t *mod rn* e of the ı d t n c l th ıg ı ≡ s t m of intern l mb ti n ngine s ch a n ut m b le gı e (s IGNITION SYSTE ı) Dev ces of m lar n t ct n known as b ators ar ed s re t fi a d syn h ≡ m rt rs (e VIBRATOR)

Figu l h w a typ cal irc t d gr m f an ı d ct o l The p im ry l w ı d n th o e o ts of o ly few turn Th econdary co l w d er th p mary co t f la ge mber f tu Whe the w tch S ı I d th

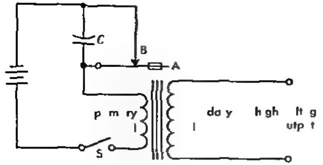


Fig. 1. Typical circuit for an induction coil

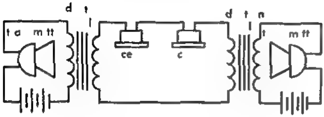


Fig. 2. Induction coils in telephone circuit

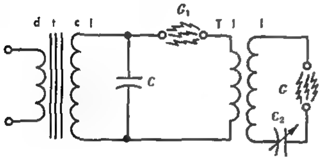


Fig. 3. Circuit diagram of Tesla coil

iron core becomes magnetized and attracts the armature A. This automatically breaks the circuit to the coil through contact B and the armature. The armature is returned to its initial position by a spring and again makes contact with the contact B, restoring the circuit to the primary coil. The cycle is then repeated rapidly.

While current is flowing in the primary coil, a magnetic field is produced. When the contact between A and B is broken, the magnetic field collapses and induces a high voltage in the secondary coil, similar to transformer action (*see* TRANSFORMER). The self-inductance of the coil must be limited; therefore the core is a straight bundle of iron wires, which minimize eddy current losses, rather than a closed iron circuit as is used in a transformer.

The capacitor *C* is placed across the breaker contacts to reduce the voltage across the contacts at the moment of their opening and thus reduce sparking. Sparking is caused by the induced voltage in the primary winding resulting from the collapsing magnetic field. The capacitor allows some of the energy of the magnetic field to be converted into electrostatic energy in the capacitor rather than into heat at the contacts.

Induction coils of a different type are used in telephone circuits to step up the voltage from the transmitter and match the impedance of the line. Therefore no interrupter contacts are necessary. The battery and primary winding are connected in series with the transmitter as in Fig. 2. The secondary winding and the receiver are connected in series with the line. This circuitry reduces the required battery voltage.

Still another type of induction coil, called a reactor, is really a one-winding transformer designed to produce a definite voltage drop for a given current (*see* REACTOR, ELECTRIC).

In 1892 Nicola Tesla used a form of induction coil to obtain currents of very high frequencies and high voltages. The oscillatory discharge of a Leyden jar was used as the interrupter. The terminals of the secondary of an induction coil are connected, one to the inner coating and the other to the outer coating of an insulated Leyden jar C_1 (Fig. 3). The circuit is completed through the primary winding of the Tesla coil and the primary gap C_1. The primary of the Tesla coil consists of a half dozen turns of wires wound on a nonmagnetic core. The secondary consists of many turns. The two coils are separated by air or oil as insulation. The alternation from the Leyden jar may have a frequency of several million cps. Hence the current induced in the secondary is not only of high voltage but also of very high frequency. [C.C.]

Induction heating

The heating of a nominally electrical conducting material by currents induced by a varying electromagnetic field.

The principle of the induction heating process is similar to that of a transformer. In Fig. 1 the inductor coil can be considered the primary winding of a transformer, with the work piece as a single-turn secondary. When an alternating current flows in the primary coil, secondary currents will be induced in the work piece. These induced currents are called eddy currents. The current flowing in the work piece can be considered as the summation of all of the eddy currents.

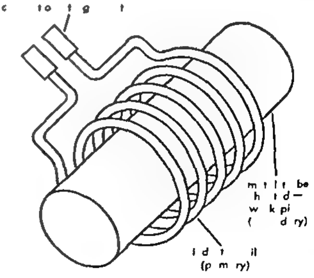


Fig. 1. Basic elements of induction heating

In th des g f c n entı al f trical appa a t th l e d t d ed eddy cur e t e m nım zed beca e they reduc the r ll effi ı ncy (*See* CORE LO S) H wever ın d t on h at g th ır max mum effe t s d ed The e- f cl sp ng u d between th ınd t r l and the wo k p ec and h gh c l urr nt a used t It the m ımum ı du ed edd rr nt a d th f re h gh he t n r t

Applications I duct n h atı g ı widely em pl ed n th met l w rking nd try to heat met l f ld ring brazıng ne l ng harde ıng and f r ı d t n m ltı g d ı t g

A mpared t othe entı nal p oces es ıt h these ınh r nt d t g

1 H at g nd ced d ectly ınto the m terial It ı th ef a ext emely ap d method of he t ı g It ı t l r ted by th elatı el l w rate of h t d fft ı n m n entı nal p oces es u n ur f ee t ct ad a t h at g meth d

2 Bec e f k n effe t the he t ng s local ed a d the he ted ı e ly ontr lled by th hape nd e f the nd t)

3 Indu t n he t ng a ıly e ntr l bl e ltı g ın u f rm h gh q l ty f the p du t

4 It le d ıt elf t aut m t n. l e pro e ı g a d aut m t c proces y l contr l

5 Start up time h rt and tandby lo ses a e l w non x t t

6 W k g o d tı are better b can e f the al se e f n t fumes and radı ted he t

The ınduction heating process The ınd c d rrent ın th w k p e fl w oughly p rallel t th re t th d t r e l turn

Beca f th kı eff t these ınd ced cu re t e t te n r tl fa e f the wo k pıece Th ffect depth f t pe et at ı g t f l e f q e ıes th n f h gh f e- q n d gr at f hıgh e t ty met l th n f l w ıt t m t l In m gn t m t l u b teel th d pth f cu re t penetr t n less b l w th C e te per t (pp ox m t l 1350 F wh th t el ı mag t) than t bo th C e t mp ratu *S* CURIE TEM ıı TURE ı G ETIC SK EFFECT

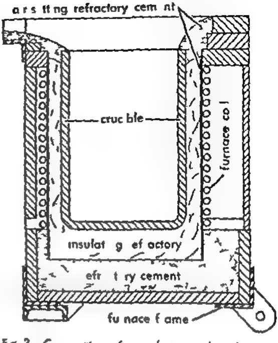
F ff ı t h at g th f qu ncy u ed m t b h gh en gh t m k th d pth f c rr t p n t a t d ably l s tl th th kn f th wo k p e m a ured at ght angles to the o l t rns The a c mpa yı table h th ra g f f equ n u ed for appl ations f the ı dı ct n heatı g p ess *S al o* DIELECTRIC HEATING

I m s he t g appl catio s the l west fre- qu ncy c n tent w th effici nt h atın ıs d b a e as rul the n t ıl t of quipment g es up w th f equ nc

Whe th work p ec re all wl en t ıs de ı ed t oncentrate tl h tı g n ar the u f ce as n s fa e h den g ıt n es ary to u e h gh r f eque c es e en thou h ffici nt p w r t an fe co ld be accompl h d at om l wer f e q n)

In la ge prod ction u e s h a f g ı two pa ate fr quen ı w th p r t ı d ct co l a e mployed t ma ır ıze prod ct on at mın m m eq pm te t

Power sources The eq ıpme t u ed a pow r ou ces d p nd n the freq ency ange f r the appl c t o W l ın f eq nc (ge e lly 60



F g 2 C ct f d ct m lt g f
U d ct th m C p)

Frequencies used in ind ction d dielectric he ti g

F requ ncy f	So rce of pow	Uses
60 960	ll u t ı ge erators or co t rs	M ss nd t on heat n f f g ıng f rm tru t p e- heat ng
960–10 000	M to -generator set	Indu t n he t g f m lt h t treat g l h d
10 000–60 000	C erters	I d t f eatın f m ll scal m lt g nd t ın
100 000 0 000	V cu m t be sc l l t rs	S rf ce du t n heatın f brazıng sold ng h d nıng d tnp d w heat g
000 000–00 000 000	V cu m t be osc l lators	D lect heat ng

cycles) are used suitable transformers power fac tor correction capacitors and control equipment are required

For higher frequencies up to 10 000 cps induc tor type alternators are used These are usually driven by induction motors and are available in ratings from 7½ to over 300 kilowatts

Converters are u ed for the 10 000–60 000 cps range principally for small cale melting These produce the desired frequency by repeatedly charging a large capacitor from the 60-cycle line and discharging it through an output circuit tuned to the desired frequency The output is a train of *damped oscillations*

For frequencies above 200 kilocycles vacuum tube oscillators are used These are self excited and are complete with high voltage rectifier oscil lator tank circuit controls and instrumentation When operating from a three phase supply they put out a continuous wave of rf power

Process use Induction heating is used for many heat processes as shown in the table The construc tion of a typical melting furnace is shown in Fig 2 (*see* FURNACE CONSTRUCTION) An induction heater u ed for hardening is shown in Fig 3

Induction heating differs from other methods of *heat treating in that it heats the metals very rap* idly and that holding time at hardening tempera ture approaches zero A minimum of time is there-

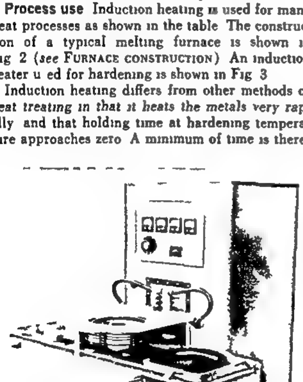


Fig 3 Manually loaded ind ct on he ter for ha d ing of gears The gear is loaded o a p dl d r the co l in the cente The sp dle ra es the g a f heat ng a d lowe s I I to a l que ch f ha de i g (West ghous Electr Co p)

fore available for metallurgical reactions, and this has a significant influence on the election of steel to be u ed *See* HEAT TREATMENT (METALS AND AL LOYS) For other electric heating methods *see* HEATING ELECTRIC [C.P.B.]

Bibliography D W Brown *Induction Heating Practice* 1956 G H Brown C N Hoyler and R A Bierwirth *Theory and Application of Radio-Frequency Heatin* 1947 J W Cable *Induction and Dielectric Heating* 1954

Induction motor

An alternating current motor in which the currents in the secondary winding (usually the rotor) are created olely by induction The e current result from voltages induced in the secondary by the mag netic field of the primary winding (u ually the stator) *An induction motor operates* lightly be low synchronous speed and is ometimes called an asynchronous (meaning not ynchronous) motor *See* SYNCHRONOUS SPEED

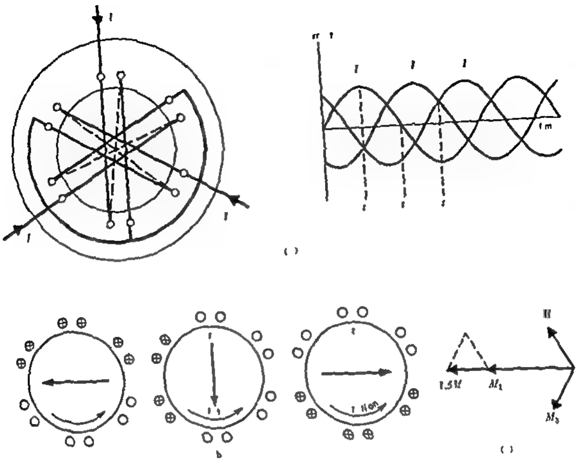
Induction motors are the mo t commonly u ed electric motors becau e of their imple construc tion efficiency good speed regulation and low cost Polypha e induction motors come in all izes and find wide u e where polypha e power is a ail *able Single phase induction motors are found* mainly in fractional hor epower sizes and tho e up to 25 hp where only single-pha e power is avail able *See* ALTERNATING CURRENT MOTOR

POLYPHASE INDUCTION MOTORS

There are two principal types of polypha e in duction motors squirrel cage and wound rotor ma chines The differences in these machines is in the *construction of the rotor The stator con truction is* the same and is also identical to the tator of a synchronous motor Both quirrel cage and wound rotor machines can be designed for two- or three-pha e current

Stator The stator of a polypha e induction motor produces a rotating magnetic field when sup plied with balanced polypha e voltage (equal in magnitude and 90 electrical degrees apart for two-phase motors *120 electrical degree apart f r* three pha e motors) The e voltages are supplied to pha e windings which are identical in all re spects The currents resulting from the e voltage produce a magnetomotive force (mmf) of con tant magnitude which r tates at synchron u peed The speed is prop rtional t the frequency f the up ply oltage and inver ely prop rti nal to the num ber of p le c n tru ted on the tat r

Figure 1a i a implif ed diagram of a three- pha e two-pole Y c nnected tator upplied with currents I_1 I and I Each stat r wi ding prod ice a pulsating mmf whicl varie ini i lally with time The re ultant mmf of the three win ling (Fig 1c) i c n tant in mag it le an l r tate at synchron u p ed Figure 1f sh w tl lirecti n of the mmf in tl tat r f r tim t_1 r an l t_3 hown in Fig 1a and h w l ow tl e r ultant mmf



O m t w d d ⊕ t w y f m d

Fg 1 Th ph d ct m t ( ) St t w d l g d u m (b) R t t g fi ld (c) Mmf p d ed by t t w d g

t tes Th y h u p d A t

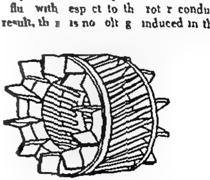
$$N = \frac{120f}{P} \text{ rpm}$$

h f th fr q n ycles p d a d p th n mb f t t poles F y g en f q f p t th t h u peed de t m ed b th mb of p le F 60 ycl f e q two-pol m t h synchr n u pe d f 3600 pm f p l m t 1800 pm a d o F d t l f tat wi d g Wi ni cs L T I III RY)

Squirrel cage rotor F gu 2 sh w the b f t g d wi g fi f qu el-c g r t r Th l r k ed gled t p ev t gg ng pe t g bel w yn l peed) nd t re- d se Th d g p d p th f r rrent th t lt l m th lt g d ed the t r la f t th t t fl Th mbe f pol n t l-c g t al equal t th mber f pol ted by th t t w d g

F g 3 h w h w th tw m t r l ment t t A ro t lockw t t f th tat r fl x ause olt ge to be i d c d in the top ba of the roto a m tw rd d rection nd in the b t t m bars in t wa d d ecti n Currents will flow i these b r in the ame d rection The e curre ts i ter t w th the tator flu a d p od ce f on the tor b in the d ect n f the t t n of the st t flux

Wh n t d i g l d th roto pp a hes ynchro n p ed A At this sp ed th is n mo- ti n f th flu with esp ct to th rot r conduc t As result, th r is no olt g induced in the



Fg 2 Sq l-c g t F i d ct m t

rotor and no rotor current flows. As load is applied the rotor speed decreases slightly, causing an increase in rotor voltage and rotor current and a consequent increase in torque developed by the rotor. The reduction in speed is therefore sufficient to develop a torque equal and opposite to that of the load. Light loads require only slight reductions in speed; heavy loads require greater reduction. The difference between the synchronous speed N_s and the operating speed N is the slip speed. Slip s is conveniently expressed as a percentage of synchronous speed:

$$s = \frac{N_s - N}{N_s} \times 100\%$$

When the rotor is stationary a large voltage is induced in the rotor. The frequency of this rotor voltage is the same as that of the supply voltage. The frequency f_2 of rotor voltage at any speed is

$$f_2 = f_1 s$$

where f_1 is the frequency of the supply voltage and s is the slip expressed as a decimal. The voltage e_2 induced in the rotor at any speed is

$$e_2 = (e_{2s})s$$

where e_{2s} is the rotor voltage at standstill. The reactance x_2 of the rotor is a function of its standstill reactance x_{2s} and slip:

$$x_2 = (x_{2s})s$$

The impedance of the rotor at any speed is determined by the reactance x_2 and the rotor resistance r_2. The rotor current i_2 is

$$i_2 = \frac{e_2}{\sqrt{r_2^2 + x_2^2}} = \frac{(e_{2s})s}{\sqrt{r_2^2 + (x_{2s})^2 s^2}} = \frac{e_{2s}}{\sqrt{\left(\frac{r_2}{s}\right)^2 + (x_{2s})^2}}$$

This equation shows that for small values of slip the rotor current is small and possesses a high power factor. When slip becomes large, the r_2/s term becomes small, current increases, and the current lags the voltage by a large phase angle. Standstill (or starting) current is large and lags the voltage by 50–70°. Only in-phase or unity power factor rotor currents are in space phase with the air gap flux and can therefore produce torque. The current i_2 contains both a unity power factor component i_p and a reactive component i_r. The maximum value of i_p and therefore maximum torque are obtained when slip is of the correct value to make r_2/s equal to x_{2s}. If the value of r_2 is changed, the slip at which maximum torque is developed must also change. If r_2 is doubled and s is doubled, the current i_2 is not changed and the torque is unchanged.

This feature provides a means of changing the speed-torque characteristics of the motor. Figure 4, curve 1 shows a typical characteristic curve of an induction motor. If the resistance of the rotor bars were doubled without making any other change in the motor, it would develop the characteristic of curve 2, which shows twice the slip of curve 1 for any given torque. Further increases in the rotor resistance could result in curve 3. When r_2 is made equal to x_{2s}, maximum torque will be developed at standstill, as in curve 4. These curves show that higher resistance rotors give higher starting torque. However, since the motor's normal operating range is on the upper portion of the curve, the curves also show that a higher resistance rotor results in more variation in speed from no load to full load (or poorer speed regulation) than the low resistance rotor. Higher resistance rotors also reduce motor efficiency. Except for their characteristic low starting torque, low resistance rotors would be desirable for most applications.

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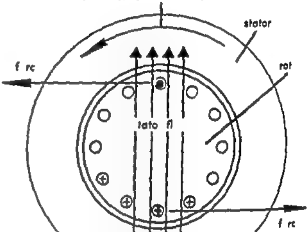

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Fig 3 Force on the rotor winding

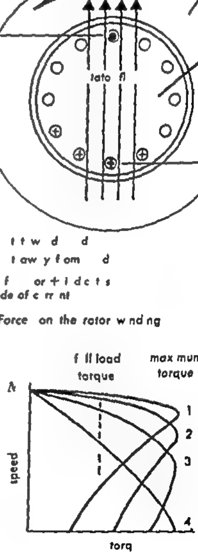

Fig 4 Speed torque characteristics of the polyphase induction motor. Curve 1 is for low resistance rotor conductors. Curves 2 and 3 are for higher resistance conductors of the rotor. Curve 4 is for conductors of resistance to produce maximum torque at standstill (maximum starting torque).

Wound rotor A w und rot r duct on motor can p o id both high t rt ng to que and good peed g lati n Th s ac ompl hed by adding xt rnal resi ta e t the r t r ci c t dur ng t rt ing a d rem i g the re i tan e fter peed s at ta ned

Th w und r t r ha a polypha e wi di g im la t the tator w d ng nd m st be wou d f th same n mb f pole Voltage are induced in these w di g j t a th y ar in the qu rr l c ge r t bars The w nd ngs are con ted t l p r gs so that connect ns may be m de t t rnal mped n es u ually est t t l mit tarti g curre t mp e power f ctor o cont ol pe d

F g e 5 ho the c nne t o f a rheo tat us d t br wo d r t r m t p t peed The rheo-tat l mit th t rti g r ent d awn f om the upply t a alue less than th t r q i ed by a q rel c g m t r The resi t c gradu lly r du ed to br ng them t r up t y ed By le g a po t n f the t rt g res tan es n the cu t, ome

Fig 5 C ct f w d t d ct n m t

Fig 6 Fl ...sociated w th th si gl -phase i duc ...ion moto

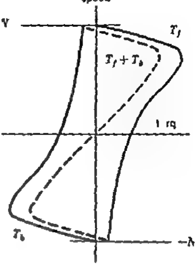

Fig 7 To q p d ed th gl -ph i d t m to

d ee of speed ontrol an be bta ned a in Fig 4 H r th s m thod of sp ed control i inherently n ffi ie t nd erts the motor i to a v ri ble-sp ed mot r r ther than an es ntially c n tant pe d moto For oth r mean of controlling sp ed of p lypha ind ct on m t rs and for other types of ac m to e ALTERNATING CURRENT MOTOR

SINGLE-PHASE INDUCTION MOTORS

S ngl phase ind ti n motor di pl y p o er p-e ating char ct ri tic than p lypha e m chines, b t a e used wh re p lyphase oltag s a e not a ail able They ar m t commo i small s z s (¼ hp o less) in dome tic nd indu tri l appl cat ons Thei partu ula d ad antag ar l w p wer fa t l w ffi ncy and th n ed f spec al ta t ng d

Th rot r f a ngle-phase ndu tion motor i of the sq irr l cag type Th stat r ha a main wind g whi h prod ces puls tin field At t nd t ll th p l t ng field ann t p d e oto u rents that will a t th ai gap fl x t p od ce rot r to que H wev r nce th ot r i t rn ng it pro-du es r s flu at r ght a gles in both pa e nd t me w th th ma n field and thereby p d ces ot t ng field comparable t that produced by the st t r of a two-ph se m tor

An e planat n f th is ba ed n the con p t that a pulsati g field i th equivale t f two p p itely rot t ng field of on half the magnitud of the es ltant pulsat g fi ld In F g 6 ϕ_m s the ma imum l e of th stator fl x ϕ whi h s hown ly by ts two components ϕ_f a d ϕ wh ch rep esent th two oppos t ly r tati g fi ld f con t t equ l m gn t des of $\phi_m/2$ Ea h c mponent ϕ_f a d ϕ pr duc t qu T_f nd T n the t Figu e 7 how that the um of the to ques wh n peed r Howe r f sta ted th m of th to ques s not a d r tation will be m i ta n d by the resulta t t que.

This machine has good performance at high speed. But to make this motor useful it must have some way of producing a starting torque. The method by which this starting torque is obtained designates the type of the single phase induction motor.

Split phase motor This motor has two stator windings: *the customary main winding and a starting winding* located 90 electrical degrees from the main winding as in Fig. 8*a*. The starting winding has fewer turns of smaller wire to give a higher resistance to reactance ratio than the main winding. Therefore their currents I_m (main winding) and I_s (starting winding) are out of time phase as in Fig. 8*c* when the windings are supplied by a common voltage V. These currents produce an elliptical field (equivalent to a uniform rotating field superimposed on a pulsating field) which causes a unidirectional torque at standstill. This torque will start the motor. When sufficient speed has been attained, the circuit of the starting winding can be opened by a centrifugal switch and the motor will operate with a characteristic illustrated by the dashed *curve of Fig. 7*.

Capacitor motor The stator windings of this motor are similar to the split phase motor. However, the starting winding is connected to the supply through a capacitor (Fig. 9*a*). This results in a starting winding current which leads the applied voltage. The motor then has winding currents at standstill which are nearly 90° apart in time as well as 90° apart in space. High starting torque and

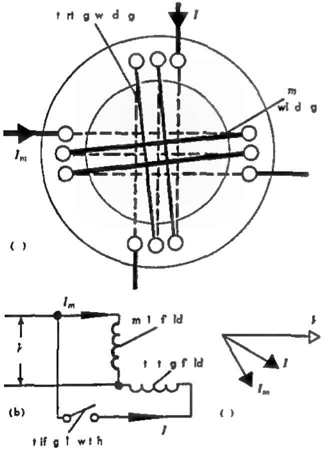

Fig. 8 Split phase motor. (a) Windings. (b) Winding connections. (c) Vector diagram.

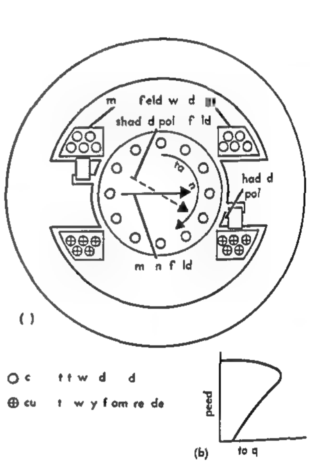

Fig. 10 Shaded pole motor. (a) Cross sectional view. (b) Characteristic.

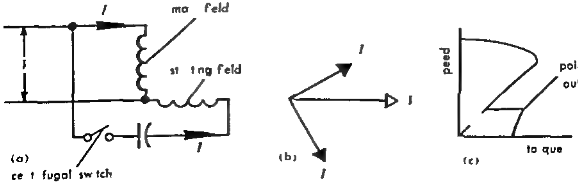

Fig. 9 Capacitor motor. (a) Winding connections. (b) Vector diagram. (c) Characteristic.

h h power fact ar ther fo btained The tart ing winding ci cu t an be pened b a centrifu al w t h wh n the m t r mes up to peed. A typ cal h a teri t is sh wn i Fig. 9c

In som m tors two ap c t rs are u ed When the m t a fir t connected t the lt upply th two pa t rs are sed i parall l in the start g c rcu t. At h h peed on capacit r i e m ed b a entrifugal w tch le m the other m series w th the t rti g winding Th m t r has h gh tart ng t rqu a d good pow r f ct

Shaded pole motor Thi m t r sed exten iv ly whe e l rg powe and larg tart ng t rque are ot requ red a i fa A sq irrel-ca e rotor s used w th a al nt pol tat r xc ted b th a pply Each al nt pol i l tted n that a po tio of the pole face can be en led by a hort rcu ted w d ng, r had n o l

The m in windin produ es a fi ld between tl poles as n Fig 10 Th had g coil act to d lay th flux pa i g thr gh them, so that it lags th fl x n th n h ded p rti ns Th gives a weeping magnet act n ac os th pole f ce and con qu tly a ros the rot r bars oppos t th pole f c nd result a t que on the r t r This t qu is m h maller th n th to q f a pl t pha e mo to but t dequ t for m ny perati n A typ l h ri ti i h wn in Fig 10b

For the ingle-pha e ltern ting-current mo t s s e REPUL O MOTO U IVER AL MOTO For syn hr nou m tors b ilt fo le-phase e HYS TE E IS MOTO R LUCTA CE MO OR. [A G CO]

Bibl g phy A F P ch te n, T C. Ll yd, and A G Conr d *Alt at e-c t M h es* 3d ed 19 1

Inductometer

A l f w t e f k wn ind t e Th ind ctan m y be f ed a th se of primary st nd rd r th nd ta m y be adj tabl by means of t hes co t n u l ari bl by means f a mov ble-c l n tructi n.

F d l w tates th t th ltag ind ed n a r t p port l t th rate f ch ng of m gn tic fl x. F r fl x ϕ link g N t rns of a rcu t

$$= N\frac{d\phi}{d}$$

If th s n f rromag et c mat n l present, th fl x ϕ i p port n l t th m gnetom tiv fo e M

$$\phi = PNI$$

Th proport n lit fact r P alled the perme- ce f th fl p th d I is th e t p g th gh th co l. Th te of ch ng of flu is equ l t NP t mes th rat f hang f urrent

$$= NP\frac{dI}{dt}$$

Bec se th portio l t f ct t th equati n d fined th d ta L

$$L = N^2P$$

The formula, so deri ed, a umes that all of the fl x link with all of the current In reality there i som flux that link with nly part of the current When the f rmula i rrected to include partial linkages N and the perm nc f th path of the flux that enters int the part al linkages a well as th complet link ges N

$$L = N^2P + N^2P$$

A tandard inductan e i co tructed by winding a co l n a f rm having dimen i n, that re table Some m terial dry o t ab-orb moi tu e over the years and co sequ ently han continu u ly in siz The mater l on which a tanda d indu tance i wound mu t not be bject t uch chan M rble a d ome ynth tics h ve been found suitable A hel al groo e is ut in th mat ri l, and th co l i placed in th s groo e

Th wir h uld be soft enough to onform to the groo It h uld be anne led so that the esi tivit and th current den ty are un f rm Th co l and t f rm are maintained at on t nt temperature to educe th tendency f r apid ind ctance aria ti n. The material selected f r the form sho ld h low t mperatu coeffic e t f expan n in add t on t negl ble l ng period hange n size

If the magn t c fi ld produced by the current in urt link w th an th r c rcuit, the voltage– ate-of-change-of-curre t lati n till h ld The pr port nality f ct r in thi ca-e i called the mutu l ind ctan e between the two i cu t Th mutu l ind ctan e represented b the s mbol M i er dentl

$$M = N N P$$

wh r N_1 and N re the numbers of turn in the respective ircu ts th t link with the c mm n flux nd P i th perme n e of the p th f the om m n flux Th m t al ind ctance i often written

$$M = k\sqrt{L L}$$

wh r L and L r the self ind ctances of th dividl al circu t, and k number less than un ty alled th co pl ng coeffici nt.

Thes equati ns with th formula f r self induct e give

$$P P_2 = k P$$

w ere P_1 i the permea ce of th p th f r flu p od ced b on ci cuit and P is the perm ance of t e path f r th fl x produ ed by the othe ir uit. If there w e n leak g flux, P_1 P nd P_{12} would ll be equ l, and k wo ld be un t

***Campbell* standard mutual inductance** This ha a primary wi d g cons ting of two coil placed a cylindrical f rm milar t that used fo th ta dard self ind ctance. On wi d ng i pla ed in th groove ne r ea h end f the f rm. The es ling pace between th coil adj ted so that the m gneti fi ld p od ced by n o l will e actly anc l that produced by th the on

This machine has good performance at high speed. But to make this motor useful it must have some way of producing a starting torque. The method by which this starting torque is obtained designates the type of the single-phase induction motor.

Split-phase motor. This motor has two stator windings, the customary main winding and a starting winding located 90 electrical degrees from the main winding as in Fig. 8*a*. The starting winding has fewer turns of smaller wire to give a higher resistance to reactance ratio than the main winding. Therefore their currents I_m (main winding) and I (starting winding) are out of time phase as in Fig. 8*c* when the windings are supplied by a common voltage V. These currents produce an elliptical field (equivalent to a uniform rotating field superimposed on a pulsating field) which causes a unidirectional torque at standstill. This torque will start the motor. When sufficient speed has been attained, the circuit of the starting winding can be opened by a centrifugal switch and the motor will operate with a characteristic illustrated by the dashed curve of Fig. 7.

Capacitor motor. The stator windings of this motor are similar to the split-phase motor. However, the starting winding is connected to the supply through a capacitor (Fig. 9*a*). This results in a starting winding current which leads the applied voltage. The motor then has winding currents at standstill which are nearly 90° apart in time as well as 90° apart in space. High starting torque and

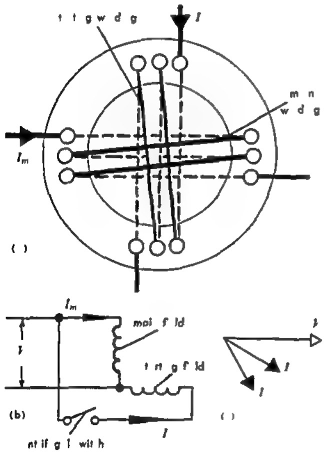

Fig. 8. Split-phase motor. (a) Winding. (b) Winding connections. (c) Vector diagram.

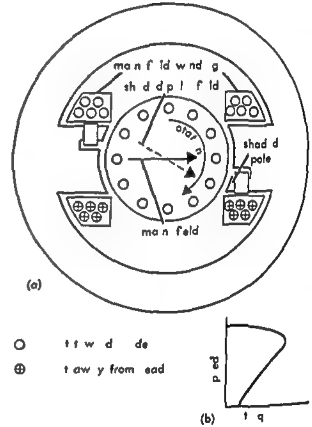

Fig. 10. Shaded-pole motor. (a) Cross-sectional view. (b) Characteristic.

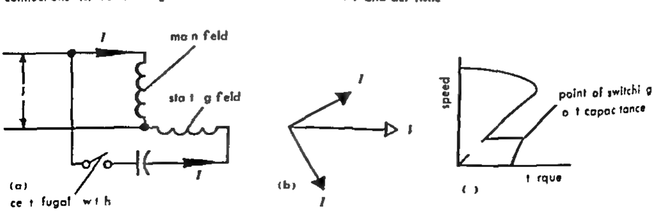

Fig. 9. Capacitor motor. (a) Winding connections. (b) Vector diagram. (c) Characteristic.

high po m fa t ar th ef e obtained The tart m winding are t a b pened by a ce t ifugal s t h when th mot c mes up to peed A typ al cha t tc i h n F g 9c

In me m tors tw p c t rs are u ed Wh n the m t r fi t ected to the olt g pply the tw apa to ar u ed par llel in the tart g c cu t. At h gh r peed n c p c t r i e mo ed b nt f g l wit h l ng th ther in ies with the ta ti wi d ng Th mot ha high tarting t rque nd g od powe f ct r

Shaded pole motor Th m t i used exten n ly whe e la g p wer d la ge starting t rqu ar t equ ed s in fa A quirrel-c g t i sed w th a li nt pole tat ex ited by th a pply Ea h alient pole s lotted that po t n of the pole face a be en led by hort c cu ted w d n had ng oil.

The main windi prod c s fi ld b tween th pol in F g. 10 Th had n co l ct to d lay the flux pa ng thro gh th m s that m lag the fl th u h ded port This gi es sweep m magneti cti n ac os the pole face, nd c nse qu tly a os the ot h r pp it th pole f c and result n a to que th t r Th t que is m h maller tha the t rq e f a pl t ph s mo to b t it is d q at f m ny ope ti s A typ al ch r t ti h wn F g 10b

F r ther ingle-pha e alt rn tin -current mo t REPULSIO MOTOR U IVE AL MOTO F r yn hro u m t s b ilt f in le-pha HYS T ESIS MOTOR RELUCTANCE MOTOR [A G CO]

B bl g phy A F Pu h t T C Ll yd and A G Co ad *Alt att g-c e t M h n* 3d ed 19 4

Inductometer

A il f wi f k wn ndu t Th ind ri m y be fi ed a in the a e f p m ry ta d d t the ind ta e may b adj tabl by me of sw t hes, o t u lv v riabl by m an of a m bl e l c tri t n

F adays law t tes that th lt ge nduced n t p p rti n l t the r te of cha ge f magn t fl x. F r fi φ l nki g N t rns f c cu t

$$= N\frac{d\phi}{dt}$$

If th f rr m gn ti m t ri l present, the fl φ p port l t th m gnetom t f e NI

$$\phi = PNI$$

Th p porti n l ty fa t P alled th perme n f th fl p th nd I th cu t p g thr gh th l The r t of h g f fl x s qual t NP t mes th te f ch g l urr t

$$= N^2P\frac{dI}{dt}$$

Bec u th p port al ty f ct r n this eq t on d fi ed a th d L

$$L = N^2P$$

Th formula o der ed a mes that ll of the fl x li k w th ll f th c rr nt In reality th re i s me flux that l nks with nl part of the current When the form l c rrected to i cl ide partial l nka es N and the perm anc f th p th of th flux that e t rs into th partial linkages well a the c mplete l nkages N

$$L = N^2P + N_p^2P_p$$

A tandard ind ctance i con tructed by wind ng il on a f rm ha ng dime i n that are table Some material dry o t r b orb m i tu e et the ye rs a d q ently change o ti u ly in ze The materi l on which tand rd i ducta ce i w u d mu t not be s bject t h ch nge Marble a d som synthet m ha bee found u table A h li al groo i c t n the mate al and th c l is pl ced in th s groo e

The wir h ld be softe ugh t m nform t the groo e It h ld be annealed so that th resi t ity and th current den it e unif rm The coil and t f rm a mainta d t con tant tempe ature to r d the tendency f r rap d i d cta ce ar a t o Th m ter al selected fo the f rm h ld ha a low tempe tu e oeffi ent of p n in add ti to n gl gible l g period ch g n ze

If the magnet fi ld prod ed by th current i ne c rcu t links with a oth r c r u t the oltage-ate-of-ch nge-of-c rent rel t n t ll h ld The m port onal t f cto in this c e called th m tual i d ctan between the two ci uit The m t al nd ctance rep esented by th symbol M is ev dently

$$M = N_1N_2P_2$$

wh re N a d N are th n mbe s of t rns in th respecti e circu t that li k with the comm n flux d P_2 s the perm a e f the p th f the com mon fl The m t al ind t ce is ft n writt n

$$M = k\sqrt{L_1L_2}$$

wh r L_1 a d L are th lf ndu t es of the nd vid l t and k is a n mbe les than unity lled th upling coeffic ent.

These q ti w th tl e f rmula for self ind ct g e

$$P_1P_2 = k^2P$$

wh P th p rm e of the path fo flu p oduced by n e uit nd P i the perm n e of the p th f r the flux p odu ed by the th cur cu t If the w e n leakag flux P P a d P w uld ll be qu l a d k would be nity

Campbell standard mutual inductance Th h s a p imary winding con t ng f tw ils pl ed n a cylindr l f rm imila t that u d f th t nda d lf indu t O e w nd ng is pl ed in th groo n h d of th form The e ulting p c between the c l adju ted o th t the magn ti fi ld prod ed by o o l will x tly cancel that p odu ed by the ther n a

ring concentric with the supporting cylinder The flux density in the neighborhood of this ring is very low A secondary winding is placed on a form that supports it centered as nearly as possible on the zero-field ring Any inaccuracies in placement of the coil or subsequent slight displacement will have nearly negligible effect on the flux enclosed and consequently upon the mutual inductance

Ayrton and Perry inductometer This inductometer consists of two coils (see Fig 1) One is wound *on the outside of a spherical form* the other is wound on the inside of a spherical form The first coil on its form is placed inside the second coil on its form The inner coil can be turned through 180 to change the direction of the mutual linkages and the sign of the mutual inductance If the two coils are connected in series the effective inductance is equal to the sum of the self inductances plus twice the mutual inductance

$$L = L_1 + L \;\; + 2M$$

The spherical forms make it possible to have the individual inductances as well as the maximum

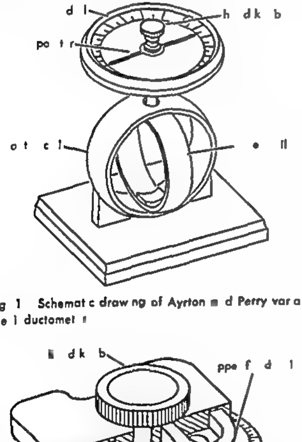

Fig 1 Schematic drawing of Ayrton and Perry variable inductometer

Fig 2 Schematic drawing of Brooks variable inductometer

mutual inductance all nearly equal This tends to increase the maximum effective inductance of the series combination More important it results in a minimum effective inductance of nearly zero. A disadvantage of this construction is that the calibration of the effective inductance L for angular displacement θ between the two coils is irregular Interpolation is always unsatisfactory with an irregular calibration Linear interpolation generally cannot be used If the scale is always set on a *calibrated point to avoid interpolation the inductometer in use is no better than one that is varied by means of switches*

Brooks variable inductometer This inductometer provides a nearly linear scale It consists of four fixed coils and two movable ones (see Fig 2) The two movable coils side by side in a plane are sandwiched between two pairs of fixed coils With the movable coils directly between the fixed coils the mutual inductance is a maximum By moving the coils in their plane so that the coil previously between two particular coils is placed between the other two coils the mutual inductance is again a maximum but its sign has been changed As in the Ayrton and Perry device the series connected inductance is

$$L = L_1 + L \;\; + 2M$$

By using link shaped coils of special design it is possible to obtain an inductance whose calibration is quite linear over most of the range The calibration departs from linear a slight amount near both ends of the scale

The sandwich type construction of the Brooks inductometer contributes to the stability of its calibration Any tendency for axial displacement of the movable coils from two of the fixed coils will be accompanied by a similar displacement toward the other two fixed coils making the net change in mutual inductance negligible *See* INDUCTANCE INDUCTANCE BRIDGE INDUCTANCE MEASUREMENT

[H SO]

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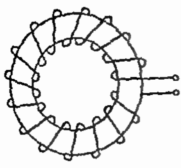
Inductor

A device for introducing inductance into a circuit The term covers devices with a wide range of uses size and type including components for electric wave filters tuned circuits electrical measuring *circuits and energy storage* [illegible]

Inductors are classified as fixed adjustable and variable All are made either with or with[illegible] magnetic core Inductors without magnetic core are called air-core coils although the actual core material may be a ceramic a pl[illegible] or some other nonmagnetic material Inductors with magnetic core are called iron-core coils A wide variety of magnetic materials is used [illegible] contain very little iron Magnetic cores for inductors for low frequency or high energy storage use are most commonly made from laminations of



T d l l

l c n ste l Some i n-co e ndu tor with res of c mpr ed p wdered r n p wde ed pe malloy r fe t m u table f r higher fr quen y ppl t ons

Fixed inductors In fix d du t r co ls r wo d so th t the t r s r man fi ed n po t n with pect to a h other If an r n c e used a y a r g p t has also fi ed and the pos t on of th co ma n n h ged w th n th ol

A t roid l oil fix d i du tor w und un f rmly nd a t dal f rm Bec u e of the el d magn t c c cut, u h an d t r has p a t lly n leak ge fi and i littl ffected by the p es nc of t y magnet c field H gh c u acy t nd d du t a ommonly made th s f rm Powered co re u ed to i ease th Q f ol nd educ th ize eq red f r a sp c fied i d ct n Cer m c tor idal co l pp ried o k re ed as tanda d duct r of h gh tabil t nd ccu acy

Adjustable inductors The either ha e tap f h ng ng th umb r f t rns d d, r c n t f e al fi ed nd tor which may be t h d t arou er pa allel omb na *ti n*

Variable inductors S h d t s n t u t d so th t the effect nd ct nc ca b ha g d M s f r d g th cl de (1) ha g g th p rme b l ty of a m gnet c c (2) m v g the m gn t c c p t f i, w th re pe t t the co l the r ma nde f th o e nd (3) m g m e c ils f the ndu m w th espect t n m of the oth c ls th r by h g g m t al du t n S A TER TIV CURRE T RCUIT H ORY I DUCT NCE

[B L R W S P]

Industrial control

Co t d b dg t nt l p ocedu es mport nt lem t f r d t l c t l l d tral r l p n ly d d t ted t r l t nt the ses l lev l f m n g me t, n bles p fit bl oper t on i compet f ld a d res a c m p y s abl ty t dju t t i d try h ng d t e c m t t

Cost control U f c t a u ti g f c ntrol d es f m th b l ty i d t rm t in te ms f t m a a d p oduct, p t or p ocess a d t mp thes is t predet m ned est m tes o tandards The m re comm n st systems are j b or o de c t product c ts proce co t and tandard t

With j b n rd r c t each cust mer s order translat d in turn int a plant production order is d t rmined eparately fr m all other order Charges f r di ect material and d rect labor are r c rded again t the plant order tog ther with bur d n n the ba s of di ect labor d llar d rect labor ho s or machine hou s The jol or der co t system i ed p nc pally in jobl ng h ps in which the nd idual rders vary greatly

Product-co t system is employed m c mpanies wh ch prod ce a l ne of regular products Cost may b determ ned by part number and l y opera ti n Final un t c ts a e obt i ed b di iding the gg gate mate ial lab r and burden costs by qu ntiti s prod ced

Process co t ppl cable to proce pl nts in th ch mical mi ing pap r and m lar indu tries The th ee elem nts of co t (mat r al labor and b de) c n be di ided by a c mmon unit f mea u e s ch as pou ds feet or gallons Such u t p c s c st can be de eloped f rther by opera tion

Sta dard c sts a e b ed m *predetermined* co t sta d rd uch osts m y be u ed in a y of the f reg g system alth ugh nly in egment f the u ual j b-cost system Standa d cost e defi ed as th appl cable t n rm l produ tio taking into acco nt cu r t nd a t ip ted cond ti ns which w ll affe t ope ation Mat rial ost t dard a e d el ped n the ba is f spec fic tio s con ump-ti n and p es t and futu e pric Labor cost t nd rds u ually ar determi d f om related time t d es P ed *termined* dep rtm ntal b den rates a e lculated on the bas , f co dit ns e pected t prera l St nd rd st procedures nd the n f rm t e a nce accou t which can be devel oped u ref m f g at al e in c ntr ll ng c t a d imp g ope ating effi iency

Budget control Co trol f any c nt nu g ac t ity f tered by b dg tary procedures that ge te the f llow d nt es (1) u d g al ( ) op ting plans rd ated with f n n l n ce (3) ts a t l f r imp oved c n trol (4) a m nim um of w teful nd haph rd op at n (5) sou d pla ng based on enf ed e amn t n f f t re c ndit ons d (6) c m p n f tual pe f ma ce w th pr mises nd p ed t mined est mates B dg ts a e n me ou i h cre and in th r ppl b l ty t arious a t t es th y a e used d ffe e tly by arious level of ma agement A budget is n estimate usually f m ney wh ch will be p nded for cert n pu p es w th n specified pe i d f time A fo ec st u ually p l e t m g al e t m t s sim lar to a b dget b r o e g l g r f t p iods O all nt gr ted b dg t a e a u ly de c bed b dgeta y c r l s p og mmi g mply as c ntr l

An feme t of f nd me tal imp t ce t budget nt ol l es i the p y hol mpl yed i th d

ring concentric with the supporting cylinder The *flux density in the neighborhood of this ring is* very low A econdary winding is placed on a form that supports it centered as nearly as possible on the zero field ring Any inaccuracies in placement of the coil or subsequent slight di placement will have nearly negligible effect on the flux enclo ed and con equently upon the mutual inductance

Ayrton and Perry inductometer This inductometer consists of two coils (see Fig 1) One is wound on the outside of a spherical form the other is wound on the inside of a spherical form The fir t coil on its form is placed inside the second coil on its form The inner coil can be turned through 180 to change the direction of the mutual linkages and the sign of the mutual inductance If the two coils are connected in eries the effective inductance is equal to the sum of the self inductances plus twice the mutual inductance

$$L = L_1 + L_2 + 2M$$

The spherical forms make it po sible to have the individual inductances as well as the maximum

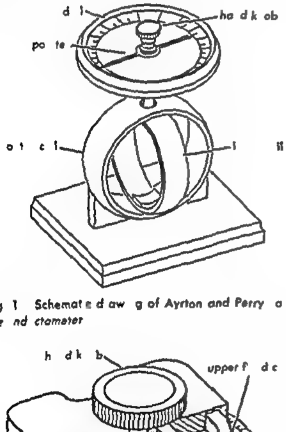


Fig 1 Schemat c d aw g of Ayrton and Perry a ia ble nd ctometer

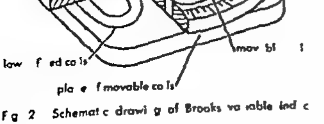


Fig 2 Schemat c drawi g of Brooks va iable ind c tometer

mutual inductance all nearly equal This tends t increase the maximum effective inductance of the series coml ination More important it results in a minimum effective inductance of nearly zero A disadvantage of this construction is that the calibra tion of the effective inductance L for angular di placement θ between the two coils is irregular Interpolation is always unsatisfactory with an ir regular calibration Linear interpolation generally cannot be used If the scale i always set on a calibrated point to avoid interpolation the in ductometer in use is no better than one that is varied l y means of switches

Brooks variable inductometer This inductometer provides a nearly linear scale It con i ts of four fixed coils and two movable one (ee Fig 2) The two movable coils side by side in a plane are sandwiched between two pairs of fixed coil With the movable coils directly l etween the fixed coils the mutual inductance is a maximum By moving the coils in their plane so that the coil previou ly between two particular coils is placed between the other two coils the mutual inductance is again a maximum but its sign has been changed As in the Ayrton and Perry device the series connected inductance is

$$L = L_1 + L_2 + 2M$$

By using link shaped coils of special de ign it is po sible to obtain an inductance who e calibration is quite linear over most of the range The calil ra *tion departs from linear a slight amount near both* end of the scale

The sandwich type con truction of the Brook inductometer contributes to the stal ility of it calibration Any tendency for axial di placement of the movable coils from two of the f xed coils will *be accompanied by a similar displacement toward* the other two fixed coils making the net change in mutual inductance negligil le S e INDUCTANCE INDUCTANCE BRIDGE INDUCTANCE MEASUREMENT [H SO]

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Inductor

A d vic for intr lucing in luctan e into a circuit Tl e term cover levice with a wi le range of u e size and type inclu ling omponent f r electric wave filter tune l ircuit elect i al m a uring circuit and energy t r g l i

In l ict r are cla f e l a f xe l a lj i tal le and varial le All are m le eith r w tl r witl ut mag netic c re In luct r without m gn ti ore ar calle l air c re coil alt ugh tl ti al c r mate rial may l a ceramic a pla ti r s me tl er nonmagneti material In l i tor with magn ti core ar call l iron c r il A wi l ari ty of magn tic mat rial i u l an l s n f tl contain v ry little ir n Mag ti r res f r in duct r f r l w fr q ien y an l igl en rgy t r g use are m t c mm nly ma l fr m l minati n f

ti n a d t me l s can be e tabli hed for each moti With t bles f mot on t m data t i pos- s ble t d t rmi the time equ ed to p rf rm m n al ta k

Wo k s mpl n Work amp l ng employs the and m mpl theory The p rcentage of a w rk ng d y th t an op ato w rk ng is ba ed pon the perc t g mb f b ervati ns wh ch rero d the op r to s wo ki g Th method gi a reliabl m ur f the pe entage t m that th perat r workin f suffici nt ob rv t ns ar taken By es l at ng th pace of the ope ator wh n h is ob rved t be wo k g and by rec ding the n mb r of i n t f w k p oduced during the study it i po ible to d term ne tandard t m for an p r h

Becau time tanda d appl es only t a spe fi pe at n t s nec s ary that the ope at on b standardi ed a d that a d ta l d writt n descr t n f it ppl me t th time t nda d A m plete m thods des ipt on t impo tant that h t graph r m ti n p tures re sometimes us d t pplement the writt tanda d p actice

In m ompan es the ind t al ngi eer ng d p rtm t l a mes om r all resp ns bility for el ct ng pur h g a d t ll ng new fac t ry q tpme t d gn g t ol ng and fixtures d t rmi ng n pect on pro edur a d adm n t r ng qual ty o tr l The indust al eng nee ng de p rtm t m y al o b esp nsible f r u h fu c t y b ev luatio packag ng ng e ing ffice l rms c nt ol mat r l handling d pl t l y ut

Organization I du tr l ng ee ng n u ually pla d n th m n l tu ng rg zat altho gh it m t m f und the ind t al relati or fi c l d i n A rvey of 100 c mpan es h wed that n 68% f the ca s *the ch f indus- t t l* ported d ectly to the general m ag fa t ry ma g r i e p e d nt f man la tur g

I som c mpa es ind tr al g n er g a t ties e all pla ed n ingle ind t l g n eri g d partment wh l th r firms the ndu t al n g ne ri g a t ities e dec ntralized Fo exampl offic m th ds and proced a d pape w k m pl fi at n m ght be dm n t red by the offi m ge mat al o t r d t n p ogr m by th p es ng nee d m thods a d m u ement f f t ry wo k the m ufa tu g di t n H w t c mp n e ha ng wag incent p gram t me t d d el ted a t v t re n ly lw y o t ned in a ingle d p tment M y t t es of the nd tr l f ll w d fi te p oced d some e uti e H w m thod mp v m t pr j ct and sp ci l tud es u ll t k the fo m of a pec fi on m nt w th b dg ted st establ hed and mple t n dat pecified

I d t l g e g p l M st omp es pr f i d t i l eng ee wh ha eng nee ing degree pref ably in nd tr l ng ee i g h wev bus nes adm t t and l b al graduates are ometimes employed The larg r mps es have s me people with advanced de- gr es Thor ugh traini g in t ti ti s and mathe- mati s i bec ming incre singly es e tial A urvey of 100 ompan es with indu trial engineering de- partment howed that 43% of the indu trial en gine rs are college graduates and 21% a e people wh were taken f m the hop and trained in in du trial eng neering

Pa t c pat on i cos reduction The w rk of the industri l engineer early always results cha ge When a bett r method i p posed new ma hine n w q ipment r n w procedures may be called for and s the operat rs are a ked to change th way th y ha e been doing th ng If properly ap- p oached th cooperation of the affected people an be ol tained If th people who will affected by a change part c pate in developing the new meth d and have a part in putt ng the change into eff ct th y a m re likely to s pport the change th n if it is impo ed from outside In line with th philosophy pervi ors and workers a e encour aged to m ke s ggestion for mpro ements and w th the aid f the indu tr al engin ering depart m nt t put them to effect

Te m goal app a h Participation can be car ried to a d partment or a pla t with many people acting a a team to establi h a go l a d then etting out to reach t Th i du tri l e g nee ing depart me t then eve as f ct f nd ng agen y and pro- vid taff ervic a r qui ed Thr ugh o ga izing thi g so that th rs take the in ti t e for mak g ch ng and by perfo ming q ckly and p fici ntly those duties that e equired of him by the op- erat g pe sonnel the ndu trial engineer c trib- tes to th o r all goals f the o ganization he s rves See I DUSTRIAL CO TROL METHODS EN GINEERING PLANT FACILITIES PRODUCTION EN GINEERING QUALITY CO TROL [R M BA]

Industrial meteorology

The omme cial appl cati f weather forma tion to th ope at nal p obl m f busines in d stry tran p rtat on and a r ulture in a manne int nded to opt mi e th p t with r pect t th w ther f tor Th weath r format on may cons t of p t w ath r re rd contemp ry we ther d t pred tion of nt pat d weather c ditions r a d tandi g of phy ical proc es e wh ch c ur in th atmosph e Th p ra tional p blems ar ba cally deci ns ega d ng con e of t on n wh ch s me lem nt f the weath r ts an nfluence

Beca e meteorological dat e n t a l ble to pec fy t p esent nd f t r te of the atmosph r w th abs l te p i n d knowl dge f phys al ce es n th atm phere is compl te th appl cat on of w th inf rmat t pe t nal d c i s is properly ewed a pecial ed c f d on m k ng in th f of unc ta nty Wh t i l ed h s be t llus- t ated by a sp fic ample d sc ed by J C Th mp in 19 0 A hyp th t cal on truct

velopment of budget segments. A budget must originate with the individual supervisor who is responsible for controlling expenditures at a particular level. Thus a plant operating budget reflecting forward estimates of departmental costs and expenses must stem from the department manager or foreman. Guidance is furnished by management, but the frequently used procedure wherein budgets are created and imposed from above falls short of its prime purpose to achieve effective control.

Budgets in their form and content are normally designed to follow the accounting classifications in use for accurate comparisons to actual performance.

An over-all budget for a divisionalized multiplant manufacturing company will consist of many segments derived from many sources within the business, culminating in final budgeted income and balance sheet statements comparable to those normally supplied to top management.

An integrated budget control includes objectives as formal statements of planned goals for one- and five-year or longer forward periods; budgets in the form of statements of proposed income and expenses and financial condition detailed by months for a one-year forward period and in more general form for the longer period, all designed to achieve the stated objectives; and performance reports that compare actual results with budget figures, together with explanations of variances.

Detailed budgets at the operating levels and the integration of these with high-level objectives and over-all budget program provide essential techniques for sound top-management action. See INDUSTRIAL ENGINEERING. [J.P.R.]

Industrial engineering

As defined by the American Institute of Industrial Engineers, "Industrial Engineering is concerned with the designing, improvement, and installation of integrated systems of men, materials, and equipment, drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems." Industrial engineering applications are to be found in offices, stores, hospitals, restaurants, hotels, and on farms. Most industrial engineering activities are in manufacturing concerns.

Functions of industrial engineering. Two major functions of the industrial engineering department are analysis and improvement of methods and the measurement and reduction of cost.

Methods improvement. The most economical method of performing an activity is developed and standardized. Then *the operator is trained to perform the job* in the specified method. Finally the work is measured and a time standard established. The process of making a part or doing a piece of work is studied before a specific operation is analyzed. When warranted, a study of worker motion may be made to find the best manual method of performing the task. A study of systems and procedures, layout of equipment, method of handling material, and flow of work are often part of such methods improvement.

Traditionally an operator, his method, and the equipment he uses were studied after a product had been designed and put into production. Today the economy of manufacture is being considered in the early stages of the design of a product and the development of its manufacturing method. Design of a product can materially affect the number of parts the product will have and the number and kind of operations required to manufacture it. Although motion and time study of work already in production produces large annual savings, even greater savings are possible by bringing the industrial engineer into the picture at the outset.

Some companies have methods laboratories in which experimental production lines and work place mockups are constructed and tested. The full force of design engineers, product designers, industrial engineers, and manufacturing groups is brought to bear on each aspect of designing a product for greatest economy of manufacture as well as for appearance, safety of operation, serviceability, and function.

Work measurement and labor cost control. Time study and administration of wage incentives for direct factory labor were originally the main functions of the industrial engineer; work measurement and labor cost control are still his major activities. To control labor costs fully it is necessary to establish time standards for each factory operation and then, through records of output, determine how well each worker performs against the standard. Such a performance index may be determined for each worker by the day or by the week. In many plants the worker is paid a wage incentive based upon his performance (see WAGE INCENTIVES). The establishment of a labor standard is a major responsibility and one that only a competent and well-trained person can perform satisfactorily.

There are four methods for measuring work which are acceptable as the basis for wage incentive. The object of work measurement is to determine the time that a qualified operator should take to perform a task when working at a normal pace. This time standard, when converted into money value, as it sometimes is, is called a piece rate. In other cases the standard time value is used as the basis for an incentive wage payment plan.

Time study. Although time study data may be obtained by a motion picture camera, machines using moving tape or a disk, or an electronic timer, the decimal minute stopwatch is most frequently used as the measuring device.

Elemental data. In departments or plants where similar but not identical operations are performed, work elements are defined and time values assigned to each. The elemental time values are established by time study or from motion time data.

Predetermined motion time data. All manual work can be divided into fundamental hand mo-

mu t be the h ape t m th d i p odu ing the de-s r d mate ial r change The market g of wa tes or th r by products of the proce may oft n erve to k ep c ts d wn Lack of demand f r a p oduct may be of l ttl on rn fo ma ket an often be c e t d wh the price of the pr duct s l w

Products S nce the ea l e t t m s mi roo gan i ms have b e u d i tent ally r otherwi e a me ns of p es rv g f od maki g them m re palatable n b ewing n the maki g of uch produ t s w ne he nd b tter a d f r ch proc d res a flax tt n (e BUTTER CHEESE WINE) The potenti l ties that m cr g ni ms ha e f the g od of m were n t pp e ated unt l World W I when th y w e ed tr p odue l o-h l ac t n butanol and rt zyme The d s-c ry of the fulness f pe c ll n d i g W rld W II ed n e orm u development of th fe m ntat n i d try a d a fuller r l zat on f the usef l es of m rob l gical a t it See ACETONE BUTANOL FER IENTATION ANTIBIOTIC ENZYME (INDUSTRIAL PRODUCTION) ETHYL ALCOHOL.

Mi roorga m ar u ed to pr du h mi al bsta ces wh h tra t d f m th ulture mi t r p fi d nd th n ed S ch ub ta es i lude (1) l ts uch a eth l a et e 2,3-b tyle glyc l (2,3-b t n d l) th al h l u h gly ol and polyhydr al oh ls (2) gan a id u h a t l et tri glu o ic a d fum (3) a bohyd at u h bo f ct a d d t n (4) itam u h B th m e nd bofla in (5) am no a d uch a l n a g ne and gl tam c acid (6) a t b t cs h p n ll st pt my t t cy l and chl mphen ol d (7) en ymes ch as am l ses pr t d glu e o d es S ACETOB CT SUBOXYDANS FER IENTATION ACETO E BUTANOL ACET E THANOL F R IE TATIO 2,3-BUTA EDIOL CITRIC A D GLUCONIC CID LACTIC ACID RIBO LA IN THIAMINE V NEGAR VITA I V B

A with all l f th a t t f m r gan m a be ed ed to a c der t on of zymes a t ng ub tr te Th d tr l m of ol g t e ed m w th th fi al p oduct h age—th m total f ct t of e f nzymes—than w th h i dual zy ch

Som f the u e al dy ment ned o rlap th wh r th p od ct t e t acted nd pu fied b t ed th li t m tu l m y s the p d i eed r b tra t d the wh le c lt e m tu be ed n fodd yea t a d f d ppl m t p od t

M oo g m ed t p od ce de i ed ha ges ert types f omp und r m t al h a n th mi r b log l tr n f rmat n f t r id b d h d g n t n h d g t by d yl t o xid t e l v ge r ed ct e r a g m i f th t r d molecul M r a nt r th es f m oo g i ms the t tle i d try w th ll n wool nd the r tti g f flax Se MICROBI LOGY S i TE TILE.

Food technology This t v l es the u e and con trol of micro rgani ms in ma y way The lea en ing of bread nd other baking products the lactic acid ferm ntat on of p ckl s oli e au rkraut and other products the ma ufacture of chee e butt r and ertain be erages—all in ol e mi rob ol g cal act t es In me a es th e pro de a mo e pal t bl product in other th y p ovid a measure of pres rvati n and in st ll othe s they achieve both Th c nt ol f unwanted micr organi ms i f gr at imp rtance a well See FOOD ENGINEERI G FOOD MICROBIOLOGY

Utilization of wastes and surpluses Th e di p al of wa te and rplu e is a ital pr blem M c obi l gical a t ty s u ed me ely to di po e of som wa tes as with s wage and is u ed with th r wastes t produ e m teri l l alue Such wa t m y be from other m crob l g cal proce ses as i th a e w th corn t ep liquor d tillers l bles whey nd oth rs It may al o be fr m ars u nonm crobi log al pr ce e uch a ug r beet m lass c g gar m ls wa te sulfite liqu r f h soluble a d c n ery wa t s O occa ion th micr biolog cal waste be ome f con id rably gr at r alue than the o ig n lly de ired prod ct i a etone b ta ol f rme t ti n the waste olids be au f the riboflavin and othe B itamin they contai ow comma d a h gher pr e than the bu ta l The n ed to di po e f vari u agri ultural u plu es for in tance tato nd ce eal g ai may make fea ible the r u e a fermentat on s b-st ate

Bioassay Th e of m croorgani ms s tool in i d t l m r biol gy must n t be o rlooked Mic ob log cal y p cedu e for vitam ns mi o ei f and nt bi ti ar in common u be au e f th ir elati e mpl ty thei pec ficity nd the p ed with wh ch th y may be rried out S BIOASSAY e l AMI O ACIDS ANTIBIOTIC VITAMIN

Types of fermentation F rme tat ns a de-t l pi f m the i gle organ m one p d ct type t tho i whi h two o mor o gan m g wn to-geth r r in eq nce may be ed Fung m b sed b ally to ac h rif tarch d rectly fol low d by anaer b c bacter al ct t t pr d c de i d p d ct I pate t d m thod of p d c g i ly the p ee rso di mi op melic acid i first prod ed b ne ga i m and th n deca b xylated by a s c d gani m t gi e ex ellent y eld f the d i ed ly i e O g i ms p od c g des able m t r als wh n gr wn t g th n one way r a the m y b nd ced to p duce rew a d en m r des bl ub t n

Other uses Th fi ld of num l f ed uppl m t tion wh th r w the e t cted mi als whole cult em tu r w t f m f rm t ton f gre t imp rtan and ne l r turn The produc t f gr wth stim l t s growth inhibitor a d fu g c des s of nc e ng imp rtanc Beca e of th a t m kets a ilabl th product on f mate-al f n th agricult r l i du t y both an

company was confronted daily with the decision whether to pour concrete. If the concrete were poured and 0.15 in. or more of rain fell in the subsequent 36 hours, damage of $5,000 would result. The cost of protecting the newly poured concrete from rain would be $400. To minimize the total expense of a series of such repetitive decisions (optimization of the operation), it follows from the principle of the calculated risk that protective measures should be taken only when $P > C/L$, where P is the probability of 0.15 in. or more of rain within 36 hours, C is the cost of protective measures ($400), and L is the contingent loss ($5,000). For this particular case, under the actual weather occurring during a season's operation, the total expense (cost plus loss) would turn out to be $85,000 if protective measures were taken, $72,800 if protective measures were taken every day regardless of anticipated weather, $32,600 if protective measures were taken only on days when there was a 50-50 chance of this amount of rain, and $24,400 if protective measures were taken only on days when the probability of the critical amount of rainfall exceeded 0.08, that is, in ratio of $400/$5,000.

This approach can be generalized to include more complex decisions, and relations have been developed by J. C. Thompson and C. W. Brier (1955) to measure the economic utility of weather information. In practice, less formal methods are frequently used and the fundamental principle described here is handled in a qualitative manner by close collaboration between the meteorologist and the user of weather information.

The substantial economic significance of weather in problems of business and industry has been emphasized by a survey conducted by the U.S. Weather Bureau in which an attempt was made to assign monetary values to the savings or profits realized through applications of daily weather reports, forecasts, storm warnings, and past weather records. The order of magnitude of the total for the United States was $1,000,000,000 annually.

Some measure of the economic toll of severe or unusual weather conditions is provided by data assembled by the National Board of Fire Underwriters, which indicated that claims totalling $866,000,000 were paid as a result of 72 major hurricanes, tornadoes, windstorms, hailstorms, and rainstorms during the period from 1949 to 1957 inclusive. These losses represent insurance losses, not total property damage, and include only instances in which claims within a single state exceeded $1,000,000.

The economic benefits that could be achieved in a single industry, the petroleum industry, by only a modest improvement in forecasts of anticipated average temperature conditions 1 month in advance have been analyzed with the result that potential reductions in tankage and inventory costs have been conservatively estimated to be approximately $100,000,000 per year. These savings would be realized by improvements in heating oil scheduling made possible through better estimates of expected space-heating requirements available from forecasts of anticipated temperature conditions.

As a result of the economic significance of the weather factor in a variety of industrial applications, there exists in meteorology a specialized activity on the part of professional meteorologists to serve the specific needs which lie outside the general public responsibilities of the U.S. Weather Bureau. This service is provided either by staff meteorologists employed by particular companies or by consultant meteorologists who work for several clients. Approximately 9% of the more than 7,000 professional meteorologists in the United States are engaged in some facet of industrial meteorology. A substantial number of these are employed by commercial airlines, where the need for specialized weather information is vital for safe and efficient operations (see AERONAUTICAL METEOROLOGY). Gas and electric utility load estimates, highway and street maintenance, outdoor construction work, marine transportation, retail merchandizing and advertizing, flood control design, air pollution, building and plant design, atmospheric corrosion, agricultural planning and production scheduling, and air conditioning and heating design are but a few of the activities in which the industrial meteorologist has found a demand for his services.

Annual conferences on industrial meteorology are sponsored by the Committee on Industrial Meteorology of the American Meteorological Society. That society has established a program for the certification of consulting meteorologists who meet rigorous standards of knowledge, experience, and adherence to high standards of ethical practice.

[T.F.M.]

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Industrial microbiology

The study, utilization, and control of those microorganisms capable of economically producing desirable substances or changes in substances.

Industrial fermentation criteria. Microorganisms to be industrially important should have certain outstanding characteristics. They should be able to grow rapidly on cheap, available substrate and to be cultivated easily in large quantities. They should be able to carry out the required transformation under comparatively simple and workable modifications of environmental conditions. They should maintain physiological constancy under these conditions and produce economically adequate yields. Above all, the microbiological method

types a d gasoline and d e el engines Liquid pe troleum h s recently been introduced a a f el in thi field C n e o k t re a ailable for exist ing equ pment and some manufa tu ers offer tru ks so-powered a orig al equ pment D rect current r qu red f r charg ng storag batt s s pro ided by motor g n r t sets o by metal di k r vacuum t be rectifiers (see STORAGE BATTERY)

El t c trucks predom ate fo operat o s in co fi ed locat o a d wh re food tuffs might be co tam n ted by exhau t f mes On open load ng platf rm and in ya ds inte nal comb ti n e gi es e empl yed for power g ndu t i l trucks

Pow ed no l ft platf rm trucks with straight and d p f ame ha long bee stand rd handli g

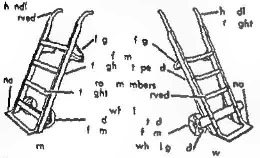

Fig 1 Tw b c typ f tw -whe l h d t k

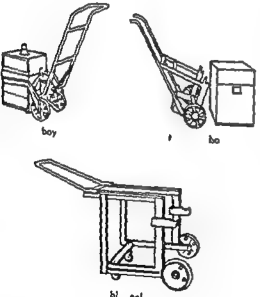

Fig 2 Low l ft h d tru k

F g 3 P w d l ft pl tf m t ks.

equ pment Relati ely new are per nnel and bur den carriers for transporting me sengers watchmen ma l blueprints as well as material between l uild ings and in plant areas cover ng con iderable ground Shop tra tors are u ed exten i ely for mi cellaneous tow ng jobs in plant and warel ou es (Fig 3) An electr nically ontrolled tract r was introduced recently it i d rected by radio or l y wi es whicl are o erhead or c ncealed in the floor

Unit load principle The un t load principle f m terial ha dling underlies the skid platform an l the pallet f rklift *method of operati n* Both meth od mo e especi lly the latt r ha e *revol ti onized* h ndl ng tech iques handling equipment and *e en* p oducti n of equipment so that they too can ac c mmodate un t loads

A unit load is not nece arily comp sed of arti cles which are trapped glued or oth rwi e uni t zed by means f binding mater al It can be m d p of any a o tment of article wh ch ar ac umulated and then handled with ut breaking b lk (Fig 4) Loads of this type w re developed or g nally to be arried on skids or pallet but the trend is to mak them up s that they can b han dled by sp c al devices which lim nate the n ed for any acc sory upporti g equipment Th e unit load p c ple has been extended as evidenced by the increas ng use of larger c nt iners and o e the-ro d tru k and trailers which are treated a u t l ad n piggy back rail nd mari e hip p ng

Skids are co st ucted in three ba ic types (1) li sk ds with fixed and swi el caste s which are too li ely fo t e ng purpo es (2) emili e skids with two fixed l gs at the front and a pair of rigid ca te s t the e r and made m b l by me ns of a jack a d (3) dead sk ds ha ing e ther two olid runners r fou m tal l gs (Fig 5) All wooden de d sk ds and those mad of hardwood platforms with metal edges nd metal legs are co vent nal others re made f metal such s ste l or l minum nd ha e sp ci l superstructure

Pallets d ffe from k d i h i g two de k r fa es separated by two or more lengthwise membe c ll d str nge whi h in s me c nstructions are placed by blocks The N tion l Wooden Pallet Manufactu e As oc at on has prepa ed and is u d sp c fi ati n for l mber f t ners and oth r p llet mpone ts D ff ent constr ction a e c lled by de pti e n mes (Fig 6) For ex mple thos w th double w ngs to perm t the use of l ng bars are the tevedore typ The two mo t c mm nly u ed zes of pallets are 30 by 40 n d 40 by 48 in B th can b carried ad a tageou ly er th ad t u ks and t a l s a d n box a d r l g at d cars The U.S Navy has standardized th latt

If a pall t is to be u ed with a low l ft truck the bott n deckbo rd mu t be o spaced that op i gs r l ft near both end so that the rollers in the f rk arm of the truck c n d op to the floor when th p ll t i b ng elevated Pall ts so c n tructed a e c ll d no re ible pallets (F g 6)

mal and plant, is receiving increased attention and will probably equal or surpass production for human consumption and therapy as well as the products of industrial chemical. See DISTILLED SPIRITS; FERMENTATION; ITACONIC ACID; ITATARTARIC ACID; KOJIC ACID; MALT BEVERAGE; PETROLEUM MICROBIOLOGY; YEAST; YEAST, INDUSTRIAL.
[R.H.H.]

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Industrial trucks

Manually propelled or powered carriers for transporting materials over level or slightly inclined or declined running surfaces. Some industrial trucks can lift and lower their loads, and others can also tier them. In any event, all such trucks maintain contact with the running surface over which they operate and, except when towed by a chain conveyor, follow variable paths of travel as distinct from conveying machines or monorails (see MATERIALS HANDLING MACHINES).

Running gear. The means employed to support a truck and its load and to provide rolling friction contact with the running surface is the running gear. Factors in the selection of running gear include load capacity, operating conditions, travel surface, kind of material to be handled, protection of load and machine, economy, and, in the case of hand trucks, ease of manipulation and reduction of operator fatigue.

Rollers used in dollies are of solid or tubular steel, with antifriction bearings. Rigid and swivel casters are used with dollies and with hand and powered trucks. Swivels differ from rigid types in having offset wheels and special thrust and other bearings to facilitate turning. Steel, solid rubber, semipneumatic and other wheels, fitted with plain or antifriction bearings, are designed to meet specific requirements. Industrial wheels for heavy duty and special automotive type wheels in a wide selection of tire treads are used with powered trucks and tractors.

Hand trucks. Many industrial trucks are hand propelled by pushing or pulling. Some can be attached to a chain conveyor. Others are trailers equipped with couplings and can be hauled singly or in trains, as described below. Basic types and their distinctive features are shown in the table. Two-wheel hand trucks are classified broadly as eastern and western (Fig. 1). Multiwheel hand trucks are produced in many models, but platform types continue to be the most widely used in industry and distribution. Stakes, end and side gates, solid panels, and other superstructures add versatility to the basic machines. Low-lift types elevate their loads sufficiently to clear the running surface (Fig. 2).

Powered trucks. Development of compact, high-capacity storage batteries and small internal-combustion engines made possible self-powered industrial trucks. They have been responsible for extending the scope and increasing the efficiency of materials handling operations. Sources of power include storage batteries, lead-acid and nickel-iron alkali,

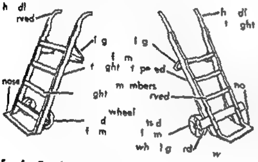
Basic types of industrial hand trucks

Type	Description	Capacity	Range
Pry 	Lever bars with long, wooden handles, short steel noses and two wheels at the fulcrum. Used singly or in pairs for moving and spotting crates and similar heavy articles as in freight cars	Up to [illegible]000 lb each	Very short distances
Dolly 	Low platform or specially shaped carriers mounted on rollers or combinations of fixed and swivel casters. Designated as furniture, milk can, paper roll and so on, to indicate intended uses	From few pounds up to 80 tons for moving machinery	A few feet
Two-wheel truck 	Normally constructed of wood and steel but also of aluminum and magnesium. Steel or wood warehouse models for general purpose, but many special purpose types, such as for egg cases, drums, paper rolls	Normally 400–[illegible] lb but up to [illegible] usually up to 1000 lb	Up to 100 ft
Multiwheel platform 	Trucks with flat platforms mounted on various combinations of 3 (uncommon), 4, or 6 rigid and swivel casters. Addition of stakes, side and end gates, solid panels, and racks, accessories increases the versatility of these trucks	Normally 1000–[illegible]000 lb for manual operation	Weight is an important factor but normally within a few hundred feet
Special 	A wide variety of trucks with special superstructures and running gear. Examples: racks of frames for plate glass and sheets of metal, frames for plate glass, boxes for small parts, and trays and shapes to accommodate bulky textile items and stock items	Same as multiwheel platform	Same as multiwheel platform

types and gasoline and d sel n gines Liqu d pe tr leum ga h ece tly been i troduc d a f l in th s fi ld Con ers n kits are a ailable f r exi t ing equ pm nt, and some ma ufactu ers offer trucks so-pow red a or g nal q ipm nt D rect c rrent r q d for harging t rage batte ies pr ded by m t r gene ator ets r by metal d k acuum tube rect fi r (s e STORAGE BATTERY)

Elect c trucks pr d m nate f r op r t on in nfi ed locati n and wl r f od tuffs m ght be ntami ted by e h ust fumes On pen l ading platf rm a d in ya d i ternal-combustion eng ne re empl yed f r powe i g nd t i l tru ks

P w red n nlift pl tform trucks w th tra ght and d p fr mes ha e lo g been standard h ndl n



Fg 1 Tw b typ s of tw wh l h d tru ks

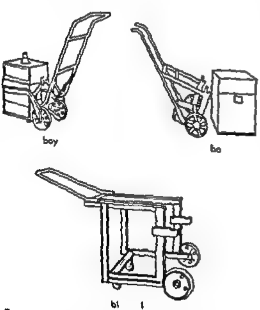


Fig 2 L w-l ft h d tru k

Fg 3 P w d l ft pl tf rm tru k

equipment Relat ely ew are per nnel and l ur d n arri rs for transporting messeng rs watchmen mail blueprints as well as materi l between build ings nd in pl nt areas covering considerable gr und Shop t a t rs are u ed ext n i ely for mis ell neous tow ng j b in plants and warehou s (F g 3) An el ctronically controlled tractor was ntroduced recently it is d rected by radi or by wires which are o erhead o concealed in the floor

Unit load principle The u t l ad principle of material handl ng underlies the skid platf rm and the p llet forklift methods of operation Both meth od mo e e pec ally tl e latter have rev lut onized handl n te hniqu handl ng equipment and e en p odu t on f equ pment s that they too can ac c mmodate unit loads

A un t load is not neces arily composed of arti cles wh h are strapped glued r otherwi e uni tized by me ns f b nding mater als It ca l made up f any a s rtment of a ticle which re a c m l ted and then handled without br aking bulk (Fig 4) Load f th s type were developed orig ally to b car ied n skids or pallet but the tre d s to m ke them up so that they c n be han dled by special de ices which elim nat the need fo a y a essory supporting equipm nt. The *nit l ad pri ciple* h s been extended as evide ced by th increasi g e f la ger containers and e the- ad trucks and traile s which are treated a n t lo d in p ggy ba k r il and mar ne h p-p ng

Skids a e c n tructed three b sic types (1) l e *skid* w th f ed and swivel casters wh ch re t l vely f r ti ring pu po (2) s mil e k*ids with two fixed l* gs at the front and a pair of rig d ca ter at the re r and m de m b le by means f a ja k a d (3) dead k ds hav ng e th two s l d runn rs r f ur met l l g (Fig 5) All wooden d ad k ds and th e made of hardwood platform w th met l edges and metal legs r c n e t onal other ar m de of m tal ch s steel o lum n m a d hav special up rstru ture

P llet d ffer f om skids n h i g two decks o fa es epa ted by tw r m re le gthw s members alled tr ng whi h in s me c n tru t ons are epl d by block The Nation l Wooden Pallet M nufa t re s As oc at on h s p ep ed and i ued p fi t n f r l mber fa t ners, and ther p llet omp nents D ffe nt co tru tio a called by d s ripti e am (Fig 6) F r xample thos with double wi g to pe mit the u e of sl ng b rs a the stev dore type The two m st c mmonly u ed s zes of p ll ts are 30 by 40 i a d 40 by 48 Both c n be carried d ntageously in o er the-r ad tru ks a d tr ilers nd n bo and refrigerated ca The U.S N vy h tandardized th l tter size

If p llet is to be ed *with a l* w lift truck th b tt m deckbo rd mu t be p ced that op ings r l ft n ar both e ds so that th oll r in the f rk arms of the tru k can d p to the floo wh n th p llet b *ng ele* ated Pall ts so *on* tru ted a e called n nr v rsible pallet (Fig 6)

mal and plant is receiving increased attention and will probably equal or surpass production for human consumption and therapy as well as the production of industrial chemicals *See* DISTILLED SPIRITS FERMENTATION ITACONIC ACID ITATARTARIC ACID KOJIC ACID MALT BEVERAGE PETROLEUM MICROBIOLOGY YEAST YEAST INDUSTRIAL [R H H]

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Industrial trucks

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Hand trucks Many industrial trucks are hand propelled by pushing or pulling Some can be attached to a chain conveyor Others are trailers equipped with coupling and can be hauled singly or in trains as described below Basic types and their distinctive features are shown in the table Two-wheel hand trucks are classified broadly as eastern and western (Fig 1) Multiwheel hand trucks are produced in many models but platform types continue to be the most widely used in industry and distribution Stakes end and side-gates solid panels and other superstructures add versatility to the basic machines Low lift types elevate their loads sufficiently to clear the running surface (Fig 2)

Powered trucks Development of compact high capacity storage batteries and small internal combustion engines made possible self powered industrial trucks They have been responsible for extending the scope and increasing the efficiency of materials handling operations Sources of power include storage batteries lead acid and nickel iron alkaline

Basic types of industrial hand trucks

Type	Description	Capacity	Range
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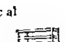
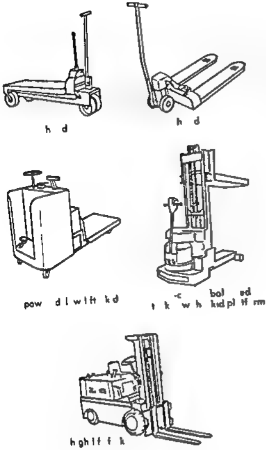
Dolly 	Low platform or specially shaped carriers mounted on rollers or combinations of fixed and swivel casters Designated as furniture milk can paper roll and so on to indicate intended uses	From few pounds up to 80 tons for moving machinery	A few feet
2 Wheel truck 	Normally constructed of wood and steel but available in aluminum and magnesium Stevedore and warehouse models are general purpose but many special purpose types are available for egg crates drums or paper roll	Normally 400–500 lb but exceptionally up to 1 00 lb	Up to 150 ft
Multiwheel platform 	Trucks with flat platforms mounted on various combinations of 3 (unstable) 4 or 6 rigid and swivel casters Addition of stakes side- and end gates solid panels and similar accessories increases the versatility of these truck	Normally 1500 000 lb f one man operation	Weight is an important factor but normally within a few hundred feet
Special 	A wide variety of trucks with special structures and *running gear* Examples are box frames for spools and sheets of metal frames for plate glass shelves for small parts and tool shapes to accommodate bar stock textile beams and stock items	Same as multiwheel platform	Same as multiwheel platform

Free-l ft ı a ımp rt t fa tor ı m ope t Th ı the d t ce th ough wh h the fo ks are ele ted before the m st tart t r Where h droom ar l w a ı bo r do ble-t e ı g ı po bl f ffi ent free-l ft s pr d d

Att chm nt for e with h gh l ft tru ks ar de-gned to h dle ı cifi pr du t gly o ı mul t pl un t Many ttachme t lım nate th need

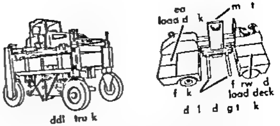


Fg 7 H d-op t d d t b l d p w d to k typ k d d p ll t t k

f a p ll t th pp t g rr f t w th d ect ec m d t g

Th ted ı ty f h gh l ft f k t k b ed th w ght f th l d p d wh h th m h l ft wh th l d t l ted pec fied d t f m the t l f es f the f ks. Th l d t th t f gr ıty f f rm l d F h t k th l d t r co d ed t be 15 f t k p t 2000 lb p ty 4 f m 2000 ı 10 000 lb 36 ı f m 10 000 t 20 000 lb d d gn t d b 20 000 lb

T d f kl ft t k des g h been t w d th pl m t f f t l t hes by t q e c n rı g sol e a d des l m h es m e c m plet ı tect n f m h t f mes th gh m ff ı t lyt m ffi d h g m t t t t p ov d bett b l ty



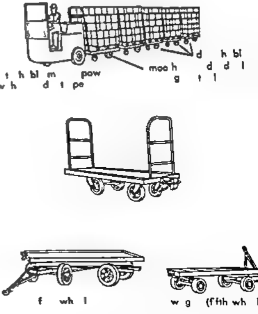
Fg 8 H vy-d ty d t l t k

Trucks and trailers Other tru ks wh ch are cap ble f h dl g u t l ads ıncl de end l ad ng (al all d g try a d t addle c rrı r) and s de l adı g type (Fıg 8) The f rm r pick up trans-p rt a d set down the r l d wl ı h re u u lly ca rıed n pallets r b l ter P p l mb r a d boxe f f t r typı al l ad These trucks an n t t e th r l ads that when t e ıng ı es en t al th y t am up with f rkl ft t ck I c ntrast d l d n tr cks can tr n p rt and a l tı r w thı the a h f th ı f k Further the m ch n s c n b eq pp d with cr n rms f r han dl ng l ngths f p p r lumber and w th re l c r r for payı ı t able a the tr ck m es fo wa d

Tra t r tra ler r tr ckle tra s a e m t ızed s on f d tr al (na w g ge) ra lr ad b t h an ad ntag r the latter f b ng ble t foll w bl path ft a el (F g 9)

I du tr l t a t p we ed el t c lly o by ın te al-c mb t o e g es re cl s fied a 3- o 4-p ı t c ntact c rd ng t the numbe of s p-portı g wh l They are u d pr m ly f erv ce l g l d g platf rm d y d operat o

Of d tr l t les s th se w th c te te r h e good t aıl b l ty (that ıs th y f ll w cl ely the



Fg 9 Eq pm t f o-pl t t t t l t kl tr

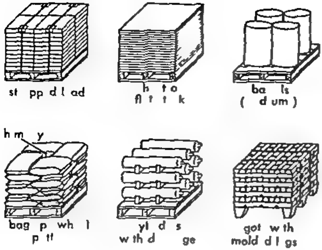


Fig 4 Loads assembled for handling a units

Fig 5 Sk ds for un t loads

Special pallets are those made of steel magne sium aluminum or even plastic expendable varie ties (one way shippers) are made of fiberboard or light wooden elements in addition to tho e with custom made uper tructures there are elf support ing types for handling crushal le loads

Structural differences between skids (Fig 5) with consideral le clearance underneath and pallets (Fig 6) with stringers and bottom boards present ing ol tructions account for the use of platforms with the former and of nece sity fork equipped machines with the latter The double deck feature of pallets makes them more suitable for multiple tiering than the runners or legs of skids which may damage the supporting surface of the lower load

Low and high lift trucks Skids and pallets are handled by self loading machines These lift trucks pick up tran port et down and in the ca e of the high lift type tier their loads without manual han dling Po ered models e olved from prototype hand machines and because the first of the self pr pelled machines were led by the operator they were called walkie The name persists even though most of them are now produced as rider trucks (Fig 7)

Lo w lift truck hand and powered lift their loads sufficiently to make them mol ile The elevating mechani m of hand types may be operated by pull ing the handle down once or several time Others have a lever or pedal perated hydraulic mecha ni m or a powered hydraulic sy tem Ga oline and electric model are a ailal le

Noncounterbalanced high lift trucks e olved fr m hand propelled tacker Fork equipped types are kno n as outrigger or traddle trucks becau e of tl e t pport which traddle the pallet All varieties c me ith fixed or tele c ping ma t The e truck are advantageous where space is at a premium For example when piling vertically from aisles these machines operate in aisles 6 ft wide compared with 10 ft ai les required by counterbalanced trucks of equal capacity Becau e they have no counterweight these machines are lighter than the counterbalanced types and hence are a boon to handling operations in old multi tory buildings

Counterbalanced lift trucks are con tructed by extending the wheel base adding counterweight and removing the outriggers They usually have forward and backward tilting masts They are u ed where outriggers cannot function advantageously but they are longer than their noncounterbalanced cou in

Forklift trucks Conventional fork trucks are made with any desired source of power the elec tion depending upon the service for which the truck is intended Elevation of the forks forward and backward tilt of the mast and the power for actuating attachments is provided by the hydraulic system Thi consists of a pump to draw oil from a re ervoir and force it through control valves which are manipulated by hand levers selected by the ma chine operator into piston actuators

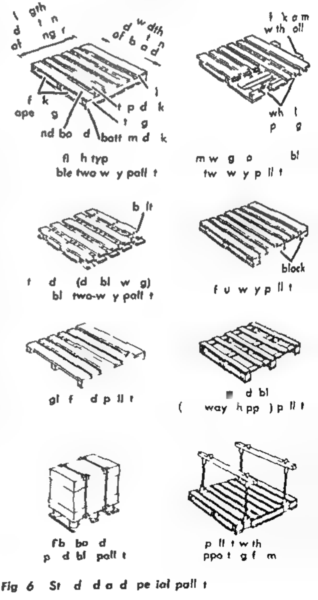


Fig 6 St d d a d pe ial pall t

Inertial guidance system

A self-cont in d h le b rn ppa atu f r en ng cha g in th moti n f v h cl A I r met s, m nt d on a gy o tabil d pl t f rm n e rv c eleratu of the eh cl a d a mp t c mpil the a ele atu n ign l t produ a c nt u l of eh cl p stu A f ed ba k t hn que k w n S h le tun b u d ertain imp tant r r nd g eatly impr s sy tem a c r cy S e NAVIGATION SYSTEMS ELECTRONIC.

In rt l gu dan y t ms a gate automatically p loted r ft lo g r n e m le h p nd subm r e Th ep c v ges of th ubmari es N ut I a d Sk te und the p lar ic ap w r m de p bl by rtial aut n v gat r

Principles of operation An i ert l y t m nav igate l k bl df ld d man be ng taken fo a r d h k ps t a k of ry t n and h g i pe d by f l l j dg th t t l d t nc nd d ect on h h bee t ke l e t l g da c u el r m t t en cha e motion gyro c pes t p d d t o r f e nd a p e i on l ck fo mput ti

A mple l met hown n Fig 1 Wh n th eh l le t m m ha g ba k b cau of t tia Th e ult ng pr g omp e on wh h p p rti l to l at on i measured ele tr lly S ACCELEROMETER

Two mp t l m nt k wn a teer t r obta n h le po t o f om le at on by m as u g t me-pl t a n F 2

F a g ti n o e fl t ea th tw ho iz tal le t te s w ld be m nted p p di la t a h th o pl tf rm a n F g 3a a d m po t nd y f eh le p s t n e mput d i

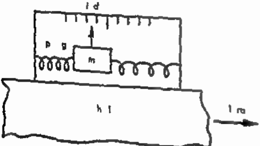


Fig 1 El m t ry l m t

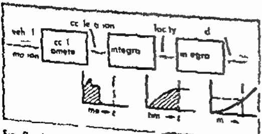


Fig 2 l g atio f a t t g l ty d in eg io f locity g ve d st

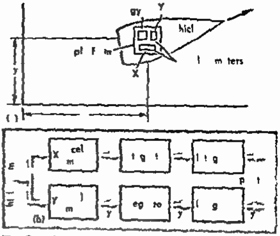


Fig 3 N g ton fl t rth ( ) G m try (b) C mput

Fi 3b Th e pl tf m s dir cti nally tabilized by gyro c p

A tual navigat on o e the urved earth i de picted i F g 4a B th azimuth angl nd platf rm t lt m st be contr ll d be au as the eh cle m ve the ugh d tanc tf ac eler mete mu t be r tat d about h zontal a is th ough angle $\phi = x/R$ whe e R is th e rth dius to keep them locally le l they w ll not en e gr ity Th a ompl hed by ng m a red veloc ty $\dot{x}$ to dr e the ac ele or te platform always t th r te $\Phi = \dot{x}/R$ hown in Fig 4b If the e a e no e r tl e acc le meters main h n ont l d pit m u e f th v h cl

The a celeromete platform is dr n f om an th r pl tf n called a tabl pl tf rm wh ch i held g l ly fixed in p e (w th gr at p eci n) by gyr p e tr ll all thre a e The t ble pl tf m s g mb l upp rted to be ng la ly nd pende t f th vehi le (GYROSCOPE) In Fig 4 locity h s b en tegrated g metric lly nd n at o al p t on a labl a platform ngle Φ o th t the t ble platf m has placed tl e fixed t rs f el tial n gat o

Schuler pendulum The t m of F g 4 a ts a e d lum be a tf (while in a t ti nary lo ati) th platf rm s tilted l ghtly off lev l a p op t o l g v ty force acting th ugh the ac e l m ter w ll dri e it back t w d le el The t m w ll o e hoot a d o cillate defi t ly with a p od

$$T = 2\pi\sqrt{R/g}$$

wh h g th ac le at n d t gra ity of f ll g body o the arth su fa T s b ut 84 m

Th b hav r d nti al to th t f simple p d l m ha ng a l gth eq al to th ad us of th e rth The tem i ll d Schuler p ndulum s a d to b Sch ler t d fte M Schuler wh h w d 1923 th t ny pendulous d ice w th th p r d w ll mai l c lly rtic l de p i m m nt f its p nt of s pport S e SCHULER PENDULUM

path established by the tractor) those with 4-wheel steer are rated as having excellent trailability but are difficult to maneuver manually and those with fifth wheel (wagon) steering are effective with heavy loads They are offered in a wide variety of constructions which makes it possible to select one with proper characteristics to meet given requirements

Each type of industrial truck is used to the best advantage when *carrying the particular load* for which it is intended Several types may be found working singly or as teams For example palletized loads *may be transported* on tractor trailer trains and then distributed and *tiered by forklift* trucks [D O H]

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Inert gases

The inert gases listed in the table *constitute* group 0 of the periodic table of the elements They *are also called the noble or the rare gases* although argon is not actually rare and helium is not rare in the United States

All these ga es occur to some extent in the *earth s atmosphere but the concentrations of all* but argon are exceedingly low Argon is plentiful constituting almost 1% of the air

All *isotopes* of radon are radioactive the longest lived having a half life of about 4 *days Ea h of the* other inert gases has at least two table (nonradioactive) isotopes in addition to one or more radioactive isotopes

All the gases are colorless odorless and tasteles s They are all slightly soluble in water the *solubility increasing with* increasing molecular weight They can be liquefied at low *temperatures* the boiling point being proportional to the atomic weight All but helium can be solidified by reducing the temperature sufficiently *and helium can be so*lidified at about 1 K by applying an external pres ure of 25 atm or more

The atoms *of* the inert gases are characterized by the fact that in each of them the outer shell of electrons is filled Therefore none of the e atoms forms chemical compounds in the ordinary sense of the word although they do form some weakly bonded clathrates and a few unstable diatomic molecules and ions Under *ordinary conditions* molecule of the inert ga es are monatomic

All the inert gases except helium and radon *produced in concentrated* form by the liquefact and distillation of air followed by *special purifi*tion proces e Helium is obtained from cert natural ga es containing 1% or more helium I don is *obtained by collecting the ga* called dium emanation given off in the radioactive dec of radium *See* ARGON ATMOSPHERIC GASE PR DUCTION OF HELIUM KRYPTON NEON PERIOI TABLE RADON XENON [C A C

The inert gases

Name	Symbol	At m numbe	At w ght
H l um	He		4 003
Neon	Ne	10	0 183
Argon	Ar	18	39 944
K ypt n	Kr	36	83 80
Xen n	Xe	54	131 30
R d	Rn	86	2

Inertia

That *property of matter which* manife ts it elf as resistance to any change in the motion of a bod Thus when no external force is acting a body rest remains at re t and a body in motion continu moving in a *straight line* with a *uniform* pe (Newton s first law of motion) The mas of a bod is a measure of its inertia *See* MASS [L N

Inertia of energy

The principle of inertia of energy state that th *inertial* properties of matter determine and are determined by *its total energy content If E is the* total energy content and m_0 the re t ma s of a piec of matter c being the speed of light the mas en*ergy relation is* $E = m_0c^2$ This formula was proposed on general grounds by H Poincare in 1900 and was deduced from the special theory of relativity by Albert Einstein in 1905

If *the mass of a body changes by an amount* Δm the corresponding energy change is $\Delta E =$ c Δm The existence of disintegration proce s in atomic *nuclei has made* it po sible to te t this formula with great accuracy Energy relea ed from nuclear reactions provides the power ource in nu*clear reactors* as well as the principal energy source in the sun and other stars The radiation emitted from the sun is equivalent to a lo s of ma s *of about 4 000 000* tons/sec

The statement that *the re t ma s of matter is de*termined by its total energy content is not u cep*tible of a simple test* since there exists no *inde*pendent *measure of the latter quantity The validity* of the general principle was adopted by Einstein as a cornerstone of his theory of gravitation Ac*cording to this theory the gra itional* properties of matter are determined by the di tribution of energy in the univer e Matter and energy are u ed as *interchangeal le term all f rm* of energy l eing *sul ject to grav tational action Phy ical predictions* made by Ein tein on the ba is of thi principle are (1) light passing near a star hould l e deviated l y the gravitational field of th tar *and (2) l ght* emitted from a ma ive star ho ild lo e energy in e *caping from* the star and c n equently should appear to be lightly reddened *with respect to a ter*restrial ource (gravitational red shift) B th the e *effects have been sul jected repeatedly t physical* test results favor Ein tein s pre lictions *See* EINSTEIN SHIFT MASS RELATIVITY [F L H]

Infant diarrhea

A mp rt t ymptom p rp sely d u d s a a ut pec d a n med l l ter ture Babi c mm ly exhib t d r h b t e t n flu d nd blood h m ll c n be fatal T atme t t ses co t l f these l es with pla eme t wh l th ca e of th d rrhe ght Sto l a n me o r at ry gr a d o ta mu u Blood g e t p fi nt r t h as b ter l r ameb c dy e t y D rh a ft n de t nf ct o Th e ev d tl t ru ı al o au at a d th t n rm l t tı l b te m be ome p tho- ge c d a e-p d cı unde c t o dı t Othe r cl d food e t ty r ll gy nd food p u h by o t m at d m lk Ep dem c d th a f the wb th descript term f a er ıt at the m l dy wh h w desp e d h p tal nu r S AMEBI IS B CILLARY DYSENTERY BACTERI LOGY ME ICAL FOOD OISO I BACTERIAL VIR LL NCE VIRUS [P L B]

Infarction

A pr s f lar b t ctı e lt g a r g of er c ll d ınfa ct Th u l se oc lu of art ry e by a thr m b mbol th d l pme t depe d t gr t t t n the ll t al e l t n If the a to- m tic blood pply ı d qu t f th el ı th l urc f bl od pply t th reg n ı f ct res lt

F ll w g a tal rıod f hyp em the ı f r t d g bec me pale B a e f the b h g g me t f the l y t m f t f the ple k d y d l g re lly wedg h p d w th th b f th w dg t the pe ph ry a d the pex t w d the point f as l b tru t S E BOLUS THROM S

W th oc l f an artery th t collat r l l t w ll ıt mpt t brı g m blood t th eg D pend th e t t f thi p es the f ted w ll b ed p l Th p oces w th th o ga ı l d Tho f

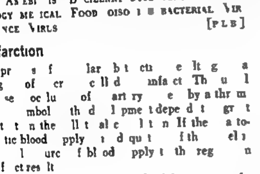
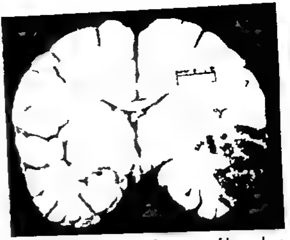
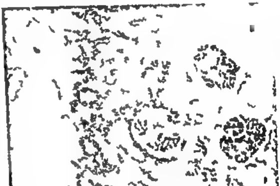


Fig 1 M g fi d gro ph tog ph f w dge- sh ped f rct f th kd y (I) Th l rt (C) med ll ry py mıd (M) d l p l (P) b l ly se



Fg 2 G ph tog ph of a sect of b h w g w dge-sh p d f t Th lt d f om a th mb f th b h f th m ddl e- b l rt ry Se d ry h m rrh g h rr d l t th f ct d t (I)



Fg 3 L w p w w f th dg f l f ct Th m t f gl m l d th gh t f th d d l t b l tll b se l th f rct d g (I) O th l ft l l t ly b tt p e- rv d gl m rul d t b l l b A f fl mm t ry ll (C) p t g th d d d l t ly b tt p rv d t

th k d y nd he rt e p le wh e tho e f the pl d l ng u lly r d With de th f the tı s th eg d d l t t n f th nearby l a dary h m rrhag m y occur

Th t th ffected ea u d rg e ag l t ec o d des Th tı d th ı f cted g b m ı flamed Soon fib obl t t ty d g nızat n b gı E t ally th d ad t r pl d by hru k dep es ed

I f r t c mm ly o ur the l g h rt lı spl en, d k d y The mm n ca e f f t f the h rt s th ombo of th co n ry t ry s ally sec d ry t rterı scler ı

I f r t f p rt f b w l w ll es lt ın d th f th ı d ıd l nl s g c l t rv nt n s f th m g As m ght b a med beca se f th f q y f th mb the ı d right n

The curved earth Schuler tuned system (Fig 4) produces accurate navigation for trips lasting many hours or days while the flat system (Fig 3) becomes inaccurate in a short time

Navigation errors Suppose for example that an accelerometer is in error by a constant value of one ten thousandth of g so that $\epsilon =$ 00322 ft/sec In Fig 3 the integrators turn continuously and the distance error grows as ϵt /2 so that after 1 hour the error (Fig 5a) is 4 miles and after 2 hours it is 16 miles In Fig 4 the output of the integrator begins immediately to tilt the platform in a corrective direction and the final platform motion is an oscillation (Fig 5a) about a position one tenth of a milliradian (006) from the true vertical with a resulting distance error between 0 and 0 8 mile after any length of time

A drifting gyroscope tilts the stable platform at a constant rate and produces an error (Fig 5b) growing as t^3 for flat navigation (Fig 3) but growing only as t (on the average) for the Schuler tuned system (Fig 4) Thus after 1 hour a gyro drift of ⅙ /day (one ten thousandth of the earth s rate of spin) produces errors of 20 miles for flat

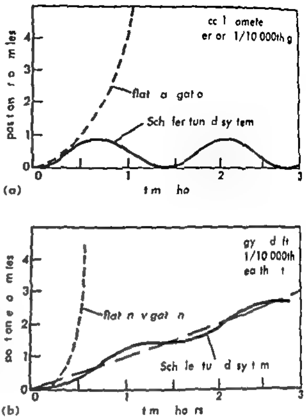
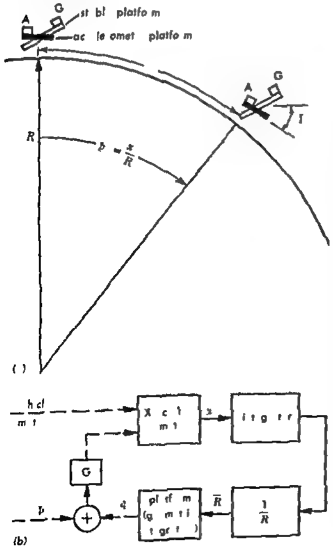


Fig 5 Inert al nav gation errors aris ng from ( ) accelerometer er or (b) gy o dr ft



Fg 4 Sch le tu ed system (a) Geom try on sphe i cal arth (b) Comput co f g at on

navigation but only 1 mile for the Schuler tuned sy tem For long term navigation the stati ti al character of gyro drift actually leads to a po ition error growing approximately as the s juare root of t

Errors in the navigation computer produce additional positional errors Computer errors ari e out of the complexities of unscrambling the mathematics of acceleration in spherical coordinates on a rotating earth and of accounting for the earth s slight nonspheri ity and other geode ic and gravitational variations *Se* EARTH GEODESY

Initial mi alignment al o produces an 84-min oscillation Alignment may be performed optically u ing a known reference or by the gyrocompa ing technique whereby the sy tem is allowed to eek gravity (leveling) and the direction of the earth s spin axis

Aided inertial systems When means are avail al le the accuracy of an inertial system may be impr ved in two ways (1) by cl eck point correc ti ns and (2) by auxiliary elocity c rrection

Check points may l e introduced by di crete re etting or continuou m nitoring u ing radio radar or automatic star tracking equipment

Independ nt velo ity data may l e ol tained from Pit t tul r D ppler rad r and serve to damp the 84-min o cillation This method require cauti n however l ecau e err rs in velo ity data produce navigati n error [R H C]

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Infant diarrhea

An mp rta t ympt m pu p sely d e ed as n ute pecifi d ea n m d al lit rat r Bab e comm ly e h b t d hea b t ext i e flu d a d blood chemic l l s an be fat l Tr tment t s o tr l f these l s w th repla m nt wh le the e f the d a he s ■ ht Stool a num r u o w tery g e a d e ta muc s Blo d pu ugg ts pecific t rt u h s ba t rial o ameb dy ent ry D rrhe ft n de tes i f ct n The i ev d n e tl at i al ■ at ■ d th t rm l ntest l bact ria can bec m pathog d e prod ing u de ert n ond ti Othe r a s cl d f d en t ity o ll rgy and food p i nt g uch by nt m ated m lk Ep dem d a h a f th n wbor the d c pt e term f r ■ t ti n th m lady wh l wid p ead h p tal n r e e *S e* AMEBI S S BACILLARY DYSE TERY BACTERI OLOGY MEDICAL FOOD POISO I ■ BACTERIAL VIR ULE C VIRUS [P L B]

Infarction

A proc s f cul ob truct r sulti g in reg o f ec i ll d a nf t Th u l l on f rt y o b a th m b s mbolus th d lopme t d pend t a gr t exte t on th ll te l ci c l t n If th stom ti blood pply i ad q t l the es l the l s of blood pply t the gio f t e lt

F ll w g t l p iod f hype mi th i fa ted reg n bec m s pale Bec u e of th b a h g a ng m t of the ula y tem f t of th pl k d ey and l g a e n lly edge- h ped w th th b f th w dge at th p phery d the apex t w rd th p nt f l b t t S E IBOLUS THRO IBOSIS

W th l n f n t y th e st g ll t e al r latı n w ll attempt to b ng m bl d t th reg n. Dep nd ng n th t i f th is p es the f r t d ea will be d p le The p ocess es w th th g l ed Th f

Fig 1 M g fi d g ph tog ph f w dge- h ped i f rct f th k d ey (I) Th l rt (C) med ll ry py m d (M) d l pel (P) ■ le ly se

Fig 2 G ph t g oph f t f b n h w i g w dge- h p d f ct Th s lted f m th mb f the b ■ of th m ddl e e- b l rt ry Se d ry h m h ge h c d l t the f ct d t (I)

Fig 3 L w p we w f the dg f r l f ct Th m t f gl m l d th gh r f th d d l t b f st ll b th f ct d g (I) O th l ft f l t ly b tt p e- rv d gl m l d t bul l b A z e F fl mm t ry ll (C) po t g th d d d l t ly b tt ■ rv d t

th k d ey a d h t e pal wh eas tho e of the ple a d l re ually ed W th d th of th t u m th on nd d l tati n of the ne by el a sec d y h mor h g may o c r

The t sue in the ffect d ea u d rg ■ g l t o a d d s Th tis ou d the in f cted r gio b m i flamed So n fib bla t a t ity a d gan zat o b gi E e t lly th d d t ue i epl c d by sh anke d pre ed r

l f t mm nly c u n th l ■ heart b spl en, a d k dney The c mm u e of i fa ts f th h rt thr mbo s f th onary rt ry sually se d ry t a t scle s

I f i n i a p rt o f bow l will result n d ath f th d id al u le s urg al i tervent n f rth m g As might b as umed beca of the f q n y of th mb i th a d ight u

ricle embolization to the lungs is a rather frequent occurrence However because of the collateral blood supply of the lungs infarction follows only when there is some interference with the circulation such as chronic pulmonary venous congestion An extensive collateral circulation also exists in the liver hence the rarity of infarcts in this organ *See* CIRCULATION DISORDERS

[R A V]

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Infection

A term considered by some to mean the entrance growth and multiplication of a microorganism (pathogen) in the body of a host resulting in the establishment of a disease process Others define infection as the presence of microorganisms in host tissues whether or not it evolves into detectable pathologic effects The host may be a bacterium plant animal or human being and the infecting agent may be viral rickettsial bacterial fungal or protozoan

A differentiation is made between infection and infestation Infestation is the invasion of a host by higher organisms such as parasitic worms *See* BACTERIOLOGY MEDICAL EPIDEMIOLOGY INFECTION LYTIC MYCOLOGY MEDICAL PARASITOLOGY MEDICAL PATHOGEN VIRUS [D N L]

Infection lytic

Infection of a bacterium by a bacteriophage with subsequent production of more phage particles and lysis or dissolution of the cell The viruses responsible are commonly called virulent phages Lytic infection is one of the two major bacteriophage bacterium relationships the other being lysogenic infection *See* BACTERIA LYSOGENIC BACTERIOPHAGE COLIPHAGE [P B C]

Infectious disease control

Since infection depends on factors in the host the parasite and the environment there are various *means by which* infectious disease control may be brought about Immunization strengthens the defenses of the host chemoprophylaxis is directed at the parasite and quarantine and sanitary measures remove the parasite from the environment of susceptible people

Immunization has been successful in controlling smallpox diphtheria tetanus and whooping cough and offers great promise in poliomyelitis It protects the individuals immunized and when the number so protected has reached a high enough level it may prevent the outbreak of an epidemic Chemotherapy is now used successfully in the treatment of many infectious diseases and is therefore effective in controlling the secondary spread of the diseases Chemoprophylaxis acts at an earlier stage it may be defined as the use of drugs to prevent the development of infectious diseases Persons exposed to tuberculosis for instance may take isoniazid with the objective of preventing the tubercle bacilli from becoming established

Quarantine may be defined as such a limitation of freedom of movement of persons who have been exposed to a communicable disease that for a period of time equal to the incubation period of the disease they are unable to make effective contact with persons who have not been exposed The term may also be used for less extreme degrees of isolation Quarantine has been effective in countries such as Australia which are distant from other centers of population so that people arriving by sea will have had opportunity to develop during the voyage any infectious disease they may be incubating Examination at the quarantine port will then be effective Quarantine is likely to be less useful as air travel becomes more common

The basic importance of sanitary measures in the control of infectious diseases is due to the fact that certain microorganisms that infect man are excreted in the feces by patients or carriers If sewage disposal is inadequate contamination of the water supply is likely Preventive measures are concentrated both on the safe disposal of sewage *and on the provision of clean water The diseases* that may be controlled by these measures include typhoid fever dysentery hookworm and infectious hepatitis *See* EPIDEMIOLOGY [C W H]

Infectious disease transmission

The transmission of infectious disease is accomplished in several ways

1 There may be direct contact with an infected person The venereal diseases are almost invariably and measles is commonly spread in this way *See* GONORRHEA LYMPHOGRANULOMA VENEREUM MEASLES YAWS

2 Certain diseases are spread by direct contact from lower animals to man an example being undulant fever which may be transmitted directly from cattle goats or swine (*see* BRUCELLOSIS) Animal ringworm is another disease in this class *See* ZOONOSES

3 Milk borne infectious diseases include typhoid fever scarlet fever summer diarrhea and bovine tuberculosis The cow infects the milk with bovine tubercle bacilli but in the other diseases listed the infection is from human sources The milk responsible is almost always raw since pasteurization properly carried out can be relied on to kill pathogenic microorganisms See MILK SCARLET FEVER TUBERCULOSIS TYPHOID FEVER

4 In the past there have been many serious epidemics of water borne diseases They included epidemics of typhoid fever cholera and bacillary dysentery and amebic dysentery As a result of chlorination these infections have been eliminated from

th wat upplies f la ge mmunit e i many pa t of the w ld S e WATER BORNE DISEASE.

5 Ga tr e te iti d e t th *Salmo lla* group f rgani ms s a food borne di ea e in certain in sta ces P rk and po ltry are p rt ul rly l able t b o t m ated and duck egg ha e been n e m t d on e al oc as Am b dy nt ry m be t a sm tted by o t m n ted eget ble S e SALMONELLA

6 A m l i fect o i n that s p e d n hosp tals An u ge t p blem t th p esent t me the pr ad f st phylococci many f th m anti b t c e t t i hosp t l Se STAPHYLOCOCCUS

7 Art 1 s wh h becom o t mi ated by n t ct with a p t nt are kn wn a f mites and the e i turn m y c u f m te-born nfe t n Am g h ld e there s c derable traffic n I by m a of toys ther t m nated obj cts wh h erv me ns f nd r t nt ct betwe n a a e and a u c pt ble a soiled l thing bedd g nd d e D e es tr m tted n thi way includ t eptoc c l fect ons nd d phth ria S DIPHTHERIA STRE OCCUS

8 Insect ve t e th m t impo t t me n f p ead g c rta d ea h a yell w feve leep ng knes plagu nd typhu Th m t f ed a e resp t ely m quitoes t et e flie fle and l e These i t a nfected but the h sefly may au e d a by ct n a pas i e c e i g rm a qu ed fr m nf cted mat i l h feces S P GUE SL EPI G SICKNE S AFRICA TYPHUS FEVER E DEMIC (FLEA BORNE) TYPHUS FE R E IDE IC (LOU E BORNE)

Host parasite relationship The t a m s of d m also b st idied as a p obl m i host pa a it el t n h p The a dynam c bala ce bet een the ffort f th pa a ite t m lt ply and th d fe f th h t ag t infect *Enviro* m ntal *fa t r* u h temp atur nd h m d ty m flu th l br m between the *two pro*- t g n t th f r th ee ets of fact ociated resp t ly w th the par t th h t d th r nm t n de ed

B t l p p l t The k cte i l popul ti n th r mi r p a m popular m y b fa ly i r t bi i g l efferts n the h t Th m f m les n this t g ry The v ru e f nfl za h w *n m ked* nt a t n th y h b t la g mi r f t a n wh h ary th t t e d th effects o tl e h t d h h p tect m n nfl za m d m m he ly p rti lly p ot t e o n t at ll p tect n n th Tl ru f A i fl nza f mpl w unl k a y th t had b n u t l er t ea th ugh th wa m d n th t ld peopl po es d a t bod es h t i d ted th h d e nt ed the m ru p em l

F t h t p p l t n The g est f n p l m d pe d l f t n th h t p p f i Th g d t b t mport nt bee u m ny m oo g n m a e lect the age g up th y n k m gococ al me g t s i m e l kely t attack younger age g oup and th e have the efore been everal epidemics n army camps in wh ch nu ne ou y ung recr ts were li i g The fact i f crowding is al o imp rtant in this ca e d ts nfluence may be s en gain in the high rat fo certain d s a e in slum over cr wded ja l and mental h pital

E t r mental fact rs N imerou en ir nmental fa t r act n b th th bacterial p p lat on and the h t p pulation Pro n f cl an w t r and p ope ewage d p s l h e l e n the ch f fa tor le ding to a ed cti n f tl e ente ic di ea s in ma y c mmun ti s A res lt of o-e lled anitary reform typho d f er is now t all unknown in modern cit es

He d immu ty Wh n a ho t is infected he may r act su c f lly to the par te nd n d ng produc ant bod e th t n ke h m immun f r me t me fr m f rthe attack f the *para ite* A well a c ns d ng th immunity of the ind dual one may al o study h rd mmunity that i the immu n ty st tus of th p pulat n a wh le If the *m* mun ty a quired to a part cular p ra ite i l t n th s sceptibles w ll te d to be c nc *ntrated in the* yo nger age group a d n ep d mi will mo tly in v l e th s ction f the *p pulat on* The *mmon* l ldhood i fe ti n uch a m a le d ch k n p x ill strat th point On the *oth r hand* the immu ty t nfl e za s h t l ed and thi di a atta ks all ag g ups

Th eshold d ity If th prop rt o f u pt bles bel w c rta r t cal value *known as th threshold d n ty* an i fect ntr du ed int th group w ll d ut Th s i an imp rtant fa tor n the cycl al l eha t r f epidemic Duri g th dem c p od the de t *of su* ceptibles dualI *inc as* a d the nd ti s bec m appr priate f a furthe *outbreak*

Nonhuman hosts So f r th h t u d r on ide t n ha b en the human but there a e ho t other th n m n wh ch may unde natural ond t o s h bor an nfe t is agent p th n for ma An ep d mi of plague in m s alway preeded by a orte p d ng outbreak n th cept de t nd *hen th* nfectio rate becom h gh i this h t tl e d sea spills o er t ma S EPI EMIOLOGY [C W H]

Infectious mononucleosis

A d a e f h ld a d p rt c larly of *yo* g dult ha ter ed by fe e and e larged lymph o d s

The ag nt pre m d but *not* p o en t be v l l ar vid ce of xp r me t l tr n mi on ha n t been bt ned

O et of th d ea l w a d no pecific with va i ble f er and mal e late cer ical lymph n d s nla g nd i *about 50%* of ca e th pl e l bec me l rged Th di e s la ts 4- 0 d ys o l ng Ep dem e ommon n in t i t wh r yo g pe ple l

Fa d gn th h i phile a t body t t i u f l Th t t based o nspe fic erol g

reaction present at high levels in patients with infectious mononucleosis Total white blood cell count and differential blood count are also useful in diagnosis *See* HETEROPHILE ANTIGEN [J L M]

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Infective dose 50

An important special case of the median effective dose is the dose of microorganisms required to cause infection in 50% of the experimental animals This is known as the infective dose 50 ID_{50} or the median infective dose In former times it was the practice to try to measure the least amount of infective agent that was needed to produce a definite infection but this proved to be a very variable quantity The median infective dose is a much more reproducible measure though it is still necessary to specify in detail certain condition to be observed during the measurement of this quantity For example the median infective dose varies widely according to the route of administration a dose that is ineffective by mouth may cause a high rate of infection when given intravenously *See* EFFECTIVE DOSE 50 [C W H]

Infinity

The terms infinity and infinite have a variety of related meanings in mathematics The adjective finite means having an end so infinity may be used to refer to something having no end To be more precise the mathematical domain of discourse must be limited

Infinity in sets A simple and basic example of an infinite collection is the cla s of natural numbers or positive integers A fundamental property of the positive integers is that after each integer there follows a next one so that there is no last integer Now it is necessary in mathematics to treat the collection of all positive integers as an entity and thi entity is the simplest infinity or infinite collection

Suppose that two collections A and B of objects can be set into one to one correspondence that is each object in A is paired with one and only one object in B and each object in B belongs to ju t one of these pairs Then A and B are aid to contain the same number of objects or have the same cardinal number This is equivalent to the ordinary meaning of the same number obtained by counting when the collections A and B are finite and is taken as the definition of this phrase in the general ca e

Now let A con i t of all the po iti e integer and let B consist of the even integers Then A and B have the ame numl er of element ince each element of A can be paired with its doul le in B thus element can l e removed from an inf nite c llection without reducing the number of it element This property di tingui he infinite collections from finite ones and indicates that the tatement the number of elements of a collecti n A is greater than the number of elements of a collection B should be taken to mean B can be put into one to one correspondence with part of A but not with the whole of A

Consider next the number of subsets of a given collection A For example let $A = \{a\,b\,c\}$ that i A consists of the three letters a b and c Then the sets $\{a\}$ $\{b\}$ $\{c\}$ $\{a\,b\}$ $\{a\,c\}$ $\{b\,c\}$ are ubsets of A To the e for convenience can be adjoined the null set containing no elements and the et A it self Thi makes a total of $8 = 2^3$ sub et It is readily proved that a set A having a finite number n of elements has 2^n sub ets Thus the number of subsets of a finite et is always greater than the number of elements By a different method the same property may be proved to hold also for infinite sets Hence for every infinite number there is a greater number In other words there exi t infinitely many distinct infinities Sets having the same number of elements as the collection of po i tive integers are called countably infinite and this is the smallest infinity

Infinity in limits of functions The term infinity appears in mathematics in a different ense in connection with limits of functions For example consider the function defined by $y = 1/x$ When x tends to 0 y approaches infinity and the expression may be written

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Precisely this means that for an arbitrary number $a > 0$ there exists a number $b > 0$ such that when $0 < x < b$ then $y > a$ and when $-b < x < 0$ then $y < -a$ This example indicates that it is sometimes useful to distinguish $+\infty$ and $-\infty$ The points $+\infty$ and $-\infty$ are pictured at the two ends of the y axis a line which has no ends in the proper sense in euclidean geometry

Infinity in geometry In geometry of two or more dimensions it is sometimes said that two parallel lines meet at infinity This leads to the conception of just one point at infinity on each set of parallel lines and of a line at infinity on each et of parallel planes With such agreement parts of euclidean geometry can be di cus ed in the term of projective geometry For example one may speak of the asymptotes of a hyperbola as l eing tangent to the curve at infinity Note that the points at infinity which are adjoined t a euclidean line or plane are cho en in a manner dictated l y convenience for the theory being di cu ed Thu only one p int at infinity is adjoined to the complex plane u ed f r geometric repre entation in connection with the tl eory of functions of a complex ariable

Other concepts Other typ e of infinitie may l e distingui hed when proj ertie other than the mere cardi al numl er of a set are l eing n i lered For example a line an l a plane contain the ame number of p int l t wl en c ntinuity c n ideration are important the line i said to l e ma le up of a ingle infinity of points wl erea the plane ha a doul le infinity or ∞^2 poi t Tl i l cau e there exi t a ne-to-one c ntinu u corre pond nce be

twee the line a d a ubset of the plane but th re does not x t such a r e ponden e letwe n the wh le pla a d the l ne or any p rt of it As an othe example an i finit t may be ordered in d ff rent way so as to h e d ffe ent rd al n m be s. ■ e CALCULUS DIFFERENTIAL AND INTEGRAL. [L.M.G.]

B bliog aphy L. M Gra es *Theo y of Fu ctions of Real I ar ables* 2d ed 1956

Inflammation

A respon e f an mal t ues to n njurion stimu lu U lly the term i applied to e ƒ n wh ch a r flected n an altered stru ture l the t ue i jured Alth ugh the mphasi i on th hang s n th nju ed focus the tatu of tl e nture rgan i m ffects th r pon ■ Othe modify g ariable nel de the agn t d durati n a d nature f tl e i jur ag nt and the sp cific s te of njury e en though the fu damental nde lyi g react ns ar th am reg rdl s of th typ f injury

The funct n ally a cr b d to this pr ce is that f defen ■ aga n t inj r ous age t and s th efo e clo el ass c t d with the pr cess f re- pa r th t e t rati f the ltered foc s t a t t app x mating th i wl ch x ted befor the j ry Although fl mmati n and epa ar fre- q ently b fici l t the rgan m ca n these respo es m y b g eat as t interfe e r ou ly w th no mal f t on a d attempts m t be m de t ppres th nflamm tory r r par ti p oc

U ually i flamm t n of a part cul r t s e o g n s nd ated t the additi f iti t the w rd root for th aff cted part Thus inflammati ■ f th l r hepa s te med h patit d of th c l col ti Th te m are furthe mod fied a t d at t l g cal age t cha t r as a ute ral hep t t r ch ni lc at ve c l t By common sage th t rm pn um ia i a epted f r infl mm ti of th lung p t cul rly wh n th u c t l ba ter al alth ugh pn um niti i u ed al

Acute inflammation The ca din l gn of n flamm t n in k n w r d b d by Cel s n th fir t t ry s bor (rednes) c lor (heat) t mo (swell g) a d d l r (p in) Late a fifth gn f n t l r l f f n ti w add d b C l n These ign n be expla ed a d ampl fied by b rvat on a imal t e r i ng t n jury

Imm d t ly f ll wing njury the bl od ap- lla es d l i nd add t nal ap ll ri s be om filled with blood This augmented blood fl w to the kin e lt n redness a d in ea ed he t The te l blood fl w l wed nd wh te bl od ell leuko- ytes, wh ch rmally r a ed n th axi ■ the fl wing t am ppro ch the m g n of th es el wall At th m t m th li g ndotl el um of th v s l bec m t ky and th whit blood cell imp g n the w ll th y bec me loo l at ta hed Th perm ab l ty f th cap llary w ll is alt ed th t w t and alt po r out f the es sels as edema fluid If the increa e i perm ability continu pla ma proteins and the attached white blo d cells along w th some red l lood corpu cles w ll pass into the extrava ular spaces and c m pr se an exudat The in rea e in extrava cular flu d whether edema or exudate cau welling and principally becau ■ of effects f pre sure on nerve e d ngs re ults in pain A the l lood flow slows and the bl d b omes more i cou becau e f lo of flu d there is an increa ed i ndency for clotting This has an effect of l elping to local ze the inflammatory agent in many ■ es The harac ter of the xudate arie depend ng on the nature of the inj rio s agent When c rtain l acter a are the cau ati organi m the ■ udate i often puru lent that i it ntain m ny polymorphonuclear leukocytes The e cell facilitate the de truct on f the ba t ria by ngulfing them into their cyto- pla m a process termed phag cytosis *S e* PHAGO- CYTOSIS

Healing This may oc ur by re olut n f the exu date if death of ti sue cells has not occur ed In thi p oce the edema fluid ■ rem ved by the lymphat c y t m and large mon nuclear white cell phag cyt e p rti ulate matter and tra sp rt t t adj cent lymph n d If e ten i e necro i of i ssue cell has ccurred healing must proceed eith r by the replacement of the lo t cells by re gene at n o by tl e dev l pme t of granulati n ti u nd ltimately the f rmation of car tis ue Gran lat on ti ue s f rmed when buds of endo- thel al ell gr w f om adjac nt cap llar ■ and fibr bla ts fr m ne rly t s e migrate into th fibr us ex d te th reby forming a network of pillari s in ■ loo e strom f fibrobla ts The fibr blast lay down coll gen a d th capill ri s bec me d mini h d E entually there i lm st compl te replaceme t by dens scar ti u

Chronic inflammation If an injur ous t mulus p rs ts f m nth or years th cla i al micro- opi p cture f a ut inflammat on is ab ent Th re i l ttle udat appar t and fewe p ly m rphonu le r le ko tes In tead the ti sues h ve a p r d minanc of la ge and mall mo onu cle ell and tl re s an nc ea in the fib ous c nnecti ti su el m nts A spec al type of b o c nflammat on is te med granul m tou in flamm t n be au of th tenden y to form nodule compo ed f fit r bla t and larg and sm ll mono- nucle r c lls O ca on lly in tub ul i ne o s l tl e central port n of th g nuloma may ■ a tr king fe ture I th s st al n organi ms may m in l e but na ■ f r many yea s Ab sces e re l cali d nflammati c taining pus that is necr tic t u ne ot c leuk cyt and u ally b t ■ If th y are located on a urface su h as the sk th y may rup t re nd dr in p tane u ly thu rel e ng the p n a d permitt ng l e l g A carbuncle s an ab e f the k n whi h d a s to th s rfac by mult ple peni g This i ult of the fact that in som loc ti s f th b dy such th ba k f the neck tough fibrou st and ex t nd p rpend cul rly t tl e kin urfac into the

reaction present at high levels in patients with infectious mononucleosis Total white blood cell count and differential blood count are also useful in diagnosis *See* HETEROPHILE ANTIGEN [J L M]

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Infective dose 50

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Now let A consist of all the positive integers and let B consist of the even integers Then A and B have the same number of elements since each element of A can be paired with its double in B thus elements can be removed from an infinite collection without reducing the number of its elements This property distinguishes infinite collections from finite ones and indicates that the statement the number of elements of a collection A is greater than the number of elements of a collection B should be taken to mean B can be put into one to one correspondence with part of A but not with the whole of A

Consider next the number of subsets of a given collection A For example let $A = \{a\ b\ c\}$ that is A consists of the three letters a b and c Then the sets $\{a\}$ $\{b\}$ $\{c\}$ $\{a\ b\}$ $\{a\ c\}$ $\{b\ c\}$ are subsets of A To these for convenience can be adjoined the null set containing no elements and the set A itself This makes a total of $8 = 2^3$ subsets It is readily proved that a set A having a finite number n of elements has 2^n subsets Thus the number of subsets of a finite set is always greater than the number of elements By a different method the same property may be proved to hold also for infinite sets Hence for every infinite number there is a greater number In other words there exist infinitely many distinct infinities Sets having the same number of elements as the collection of positive integers are called countably infinite and this is the smallest infinity

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Other concepts Other types of infinities may be distinguished when properties other than the mere cardinal number of a set are being considered For example a line and a plane contain the same number of points but when continuity and dimension are important the line is made up of a single infinity of points whereas the plane has a double infinity or ∞^2 points This is because there exists a one-to-one continuous correspondence

t ee th line a d a s ibset f the pl ne but the e does n t exi t s ch a corresp nde e between the whole pla e and the l ne r ny part f it. As an oth r ex mpl an infinite set may be ord red in d fferent ways so a t ha e diff rent rd al num be s S e CALCULUS DIFFERENTIAL AND INTEGRAL. [L.N C]

B bl g phy L. M G a s *The y of Funct ons* *J R al l nabl s* 2d d 1956

Inflammation

A r sp n e of an mal t s ues to an njuri us t mu l s U u lly th t rm is applied to r spon es wh h re refl cted n alt r d tr cture of the t ue inju ed Alth ugh the er ph s s is on the changes n the i j ed foc th tatu of the nt re orga sm affect the e pon e Oth mod fy n ariable lude the m g itude du ati n a d natu e of the i j ri agent d th p c fic site f i jury th ugh the f ndam ntal nd ly ng reacti n r the ame g rdl of th typ f njury

The fu cti n u u lly a ibed to thi p o e s th t f def s g in t i jur u ag nts a d s the f e clo ely a ociated w th the p o es f re p that is e t r tion of the alte ed f c s to a tat app x m t g that whi h x sted b f re the i j y Alth gh i flammat o a d p i a e fr qu ntly b efi l t the o g m on or as on the esp n may b o great s to nt rf re s ri ou ly w th n rmal funct o nd attempt mu t be m d t upp e s the nfl mm tory or epa ati p oc

Us lly i flamm t n f a pa t cula t sue r o g n is ind ated by th dd ti n of ti to th wo d oot f r the ff t d part. Thus inflamm n f the l h p r is t rm d hepat t s and f th colon c l t Th t r are further modif d t d rat in l g c l age t r cha a t r cute al h patit hr n c ul e colit By mmo age th t rm p e m n r acc pt d f r fl mm t f the l gs, p rt ul rly wh n th e se f ba teri l lth ugh pne m n t s i ed also

Acute inflammation The c d nal ign of in fl mm ti n k n we de c b d by f el s i the fi t e tury s ub r (red ess) al (h at) tum (w ll g) and d l r (p n) Lat a fifth g f n t l e l (fu ti wa dded by Gal Thes ign c n be e pl i ed a d ampl fied b ob erv t n n m l ti u s ea ti g to n j ry

Imm d tely f llow ng injury th blood cap ll es d l te a d dd t n l ap ll es bec m filled w th blood Th s augm nted blood flow t the kin result n edn s nd e ed h at. The at f blood fl w sl wed d wh te blood c lls l ko cytes whi h n rmally re ed in th a s of the fl wing t e m pp a h t m g n of th l w lls. At the me t me the h t n nd the l m of th es el bec m t cky n d as the white blood ll mp ng n th w ll they l e me loo l at t hed Th perm b l ty f the ap llary walls is alte ed so that w t a d alt pou ut f th es-

sels as edema fluid If the increa e in permeabil ty c nt nue plasma p ote ns and the attached white bl od cell al ng with s me red blood corpuscles will pass into the extra ascul r spaces and c m pri e an ex d t The increa e n extravascular fluids whether edema exudate c u es swelling and prin ip lly becau e of effe ts f p e sure on nerve ending results in pain A the blood flow slows and the blood b c mes more visc u becau e of lo s f flu d th re is an increa ed tendency f r cl tt ng Thi h s an effect of help ng to l calize the inflamm t r agent in many ca e The charac te f the e date v r e d p nd ng n the nature f the njurious agent. When cert n bacter a are the au at rgani m th ex date s often puru lent, that is, it contains many p lymorph nuclear leuk cytes These cell f cil tate the de truction of the ba ter a by ngulfing th m into th i cyto- pl sm a process t rmed phagocytosis *See* PHAGO-CYTOSIS

Healing Th m y occur by resolut on of the exu date f d ath of t ue ells ha not occurred In thi pro e s the edema flu d s r m ed by the lymph tic y tem and large m non clear white ells phagocyt part c l te matter and tran port it to dja ent lymph nod s If a tensi e necr sis of t sue cells h s occurred healing m st proceed ither by th eplacem nt of the lost c lls by r gen r ti n by the development of granulati n ti s e a d ult m tely the formation of ar t s G an lati n tis ue is f rm d wh n bud of e do- th li l cell grow from adjac nt capillar es and fib oblast from nea by t sue migrate into the fib in us ex d te, the eby f m ng a netw rk of cap llar es in a loo stroma of fibroblasts The fibrobl t lay d wn ollage and the ap llaries become dim ni hed E entu lly ther is alm st c mplet r placem t by dense sc tis ue

Chronic inflammation If an inju ious tim lu per i t f r m nths a y rs the lass al m cro- cop c pi tu e f a ut nfl mm t on i ab nt Th e is l ttle ex d te appare t and fewer poly m rphonuclea l ukocyte I t d th tiss ha e p edomi an e of larg and mall monon l a cells and th is an i reas n the fibr s on ect e ti s e lem is A pec l type f hr nic nfl mmat s t rm d granulomato in fl mm tio h cause of the ten l cy t f rm n d l s c mpo ed of fibrobl sts and large and mall m no- nuclea c lls Oc nally a n tube cul s s ne c os s of th entral portion of th granulom may be st iki g featu e In th tu tion org n ms may em i al e but inact e fo many years Ab- s are localized infl mm t on onta n ng pus that i n c tic t sue, necr t c leuk cyt d s ally ba t If they e l c t d n f c uch as th sk th y may uptu nd d n po t ne usly thu rel i g the p n and p rm ti g h ali g A ca b l i a ab ce s f the sk n wh ch d s to th u fa e by m ltiple pe ing Th s i a res lt of the f t that n m l t o s of the body such as th back f the ne k t gh fil u t nd te d p rp nd l ly to the kin rface nto th

subcutaneous ti sue The inflammatory proce s ex tends to neighboring compartments and acts as if there were multiple adjacent absce ses Ab cesses located deep under a urface may continue to ex pand and destroy much of the organ

Cellulitis With ome bacterial agents particu larly treptococci there is no appreciable walling off of the original lesion and the infectious agent di sects along tissue planes This is e pecially likely to occur in loose subcutaneous ti sues *See* STREPTOCOCCUS

Systemic effects of inflammation Many inflam mations may give rise to no discernible generalized reactions If the inflammation is evere there may be well recognized signs and symptoms Fever and increa ed white blood cell count may be noted even with a localized ab ce s such as a carbuncle Gen eralized abdominal pain may be pre ent in appen dicitis because of secondary inflammation of the lining of the abdominal cavity Enlarged tender lymph nodes are frequently noted in a sociation with a ute ton illitis Headache and double vision may be the first sign of a brain absce s The sys temic reaction will depend on location everity and character of the inflammatory proce s and firm generalizations cannot be made Individuals with certain hormonal disturbances such as diabetes or vitamin deficiencies such as in curvy are apt to respond poorly to inflammations particularly in fection Partial immunity to an infectious agent either through prior exposure or preventive inocu lation may modify the inflammatory reaction con siderably *See* IMMUNITY INFECTION [W S A]

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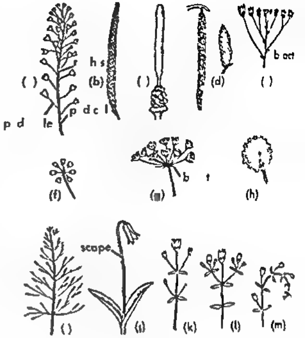
Inflorescence

An inflorescence is a flower cluster or the arrange ment of flowers on a plant It is a branch sy tem— simple if the main axis is undivided compound if the axis divides into two or more branche The stalk of the inflorescence is the peduncle the axis is the rachis and the stalks of indi idual flowers of the clu ter are pedicels The inflorescence may be subtended by a whorl of bracts called the in volucre

Types Inflore cences are cla sified as determi nate when the terminal bud forms a flower thereby arresting further growth of the axis with later flower devel ping in ucce sion from the tip to- ward the ba e or a indeterminate when the tip continues to grow forming new flower in succe sion the olde t at l a e Indeterminate types in clude the following raceme pedicels of about equal length on an el ngated axi spike similar to raceme but with se ile (without pedicels) flowers spadix a fleshy thickened pike frequently sub tended by a large bract (spathe) catkin (ament) scaly spike sometimes pendent of uni exual flow ers corymb lower pedicel elongated gi ing flat topped appearance umbel pedicels all ari e at top of peduncle and radiate like umbrella ribs



I flo escence types (a) Raceme (b) Spike (c) Spad (p stillate) (d) Catkins male and female (e) Corymb (f) S mple umbel (g) Compound mbel (h) Head (') Pan cle (j) Sol tary (k) Simple cyme (l) Compou d cyme (m) Hel co d cyme

head rounded or flattened compact clu ter of es sile flowers on a very short axis or receptacle pan icle a branched raceme

Determinate types include olitary lone flower on peduncle cyme loose flat topped cluster with central flowers opening first helicoid cyme (often referred to as corpioid) coiled cluster with flow ers on only one side of axis

Considerable confusion exists regarding the u e of the terms helicoid and scorpioid As the two types are not readily di criminated ome taxono mi ts prefer to use the older and more common term corpioid for all coiled inflore cences *See* FLOWER (BOTANY) PLANT ORGANS [N A]

Bibliography *See* PLANT TAXONOMY

Influenza

An acute respiratory viral infection usually epi demic in occurrence

Four immunologic type of influenza virus are kn wn Gr up A appears t b e ul ject to c ntinual antigenic changes gr up B change to a le er degree and C and D grou eem antigenically stalle The infectiou particle al ut 100 m in diameter may l e ina ti ated l y h at ultra iolet irradiation r formaldehyde Chick eml ry are the chief lal oratory ho ts f r tudy nd cultivati n (*see* CULTURE EMBRYONATED EGG) The iru e are capal le of agglutinating red l lood c ll from which they then pontane u ly di o iate *See* MYXOVIRUS

In human infecti n tl e viru enter the re pira tory tract in air borne dr pl t within 1 2 day inflammation of the re pirat ry tract o cur with

fever ch lls and mu culs aches A ympt m t c nfect ceu Bacter al compl cati ns may pro- d e mo e e ere llne e pecially pn umonia
D agn s by i olat on f r from th oat wa h g i oculat d into embry nat d ggs o by hem ggfut n t on nhib t ng e mpl m t fi ing r ut al zing nt b dy e po es in blood *Se* COM PLEMENT FIXATIO TEST NEUTRALIZING ANTIBODY
I flu za oce r su ce s pidemi wa e and l in pa dem c Th ant gen c shift of nfluenza *vru* n ually oc u gr dually that tra ns w de- sp ead n ne y ar e nfer ome immun ty aga n t th e p e l nt in the n xt ev r l years Howeve udd n w de a t g n hift d o cu the gr up A *iru* f th *A an i flu* a pandem c of 1957 1958 h wed ma k d tigen d ff r nce f om group A t s s of p di g y a s and f w pe ns had p t t g t b di Ep dem cs m y t rt with t an p rt t o of i us by travel ac mulat on f ffici nt numb rs of sceptibl s and mut tion f the i
Vaccines made up f r e t t a ns g own in embry nat d e g a d a t ated by form lin r ultra let l ht o f r lat ly t an ient resist an t el ted t i *S e* ANIMAL VIRUS BIO- LOGICALS [s l m]

Information theory

A b a h f c mm n t n th ory dev ted to *pr b- l m n od ng* A qu fe t e f nform ti n *theory* i t e f nume al me e f th am unt f i l mati g n d wh n th e tent f a mes age re l n d Inf rm t o theory rel h ly th matl m t l i of p babihty F r th so th term nf rmat n the v i f t appl ed l osely t ther p ob b l t tud es n e mm att n th ry u h ignal detect n nd n se and p d tio *Se* COMMUNICA TIO E ECTRICAL
Inf rm t th ry p d er te fo e mp r i g diff e t mmu i n y t m Th n d f mp r n b am n d nt du ing th 1940s A la g i ty of y te h d b e n ented t i ake b tt f x sti g es nd d pe t um al loc i (f r ex mples s MODULATIO RADIO PECTRUM LLO TIO TRANSMISSION THEORY A D METHO S) In the 19 0 th pr blem of c m pa i g t l gr ph y t m tt cted H Nyqu st nd R V L Ha tle wh pr id d some of th phi l s phy beh nd f rmati n theory In 1948 C E Sha n publ hed p ect e t l theory wh ch f rmed th b s s f h que t w k i i form i theory
In f rm t th y mm i ati n y t ms omp ted th e l f gn l ng rate Find a n ppr p i t d fin t o of ignal g r t w tself p blem wh h Sh n olv d by the u e f h m u f i f rm t i le xpla n d l i Of pecial i te t a e opt m l y tem att i a ma mum gn l g rat Opt m l sy t ms p mm y t m desig w th e- f l ab lute bounds on obta nable signaling rate Although optimal sy tems often u e complicated and expe i e encoding equipment they provide ins ght into the de gn of fast practical sy tems

Communication systems In de gning a one way c mm nicati n y tem from the standpoint of informati the ry three parts are con dered be y nd the contr l of the sy tem d igner (1) the sour e which generates mes ages at the tran mit t ng end of the y t m (2) the d tination wh ch ultimately rec i e the me ages and (3) the chan nel con i t ng of a t an m ion medium or device for c eying gn l from the u rce to the desti nation Con traints b yond the mere phy cal prop- ertie of th transmi s on med um nfl ence the de ig er F r example in de ig i g a *radio* sy tem only a g n portion of th adi freq ency spec t um may I e ava lable t him Hi transmitter p w r may ls be l m ted If the sy tem is ju t e l nk in a larger sy tem whi h plans to u e re gen ati e repe ters the de igner may be restricted t puls t an mis io cheme All u l cond ti ns a e n dered pa t of th des r pt on of the chan nel Th e d e n t u ually produce me ge in a f rm a c ptable as input by the *channel* The tr nsm tting nd f the sy tem conta ns anothe d t e lled an e code wh ch j r pares the ource s me ages f r i put t the cha n l Simil rly the re c i i g end f the y tem will conta a d code to onvert the outp t of the hannel into a form r c ogn zable by the de tin t on The encoder and dec de a e the part to be d igned In r di sys- tem th de g ts es enti lly the ch ice of a modu lator d detect r

Disc te and conti ous cases A sou ce is c lled d cr te if it me ages are sequen es of element (lett s) taken fr m an enum rable t of po sib li tie (lph bet) Thu so ce pr duc ng int ger data o w tten Engl h re d screte Sour es which are ot d c ete re alled co t nuous f r xampl sp ch and mu sou ce Likewi e ch nnels a l fi d a d s te contin ceo d g to the ki d f ignal they tran mit Mo t tran mi on m dia (uch as tr m sion l es nd adio paths) can p de conti u u ch nels h we er n t ints (s h a a re t ict n to pul e tech n q e) n the e of the e m d a m y on ert them i to d c ete ch nels

Noisel ss and noisy s s Th utput of a chan n l need not ag ee with ts input For x mple a han l might fo recy c nt n yptograph devi to rambl the mes age *S* PRIVACY SYSTEMS (SCRAMBLING) St ll if the o tput of th h el n be computed k owi g just the i put m s th the h nn l s called no s le If h wever and m g t mak the o tput ntr d t ble eve wh th inp t kn wn then th h n el i all d n i y

Encoding and decoding Many ne de s first b eak th mess g nto q e ce f lementary block ne i th y b t tut fo each block a p- r t t e code or sign l u table fo i put t

subcutaneous tissue. The inflammatory process extends to neighboring compartments and acts as if there were multiple adjacent abscesses. Abscesses located deep under a surface may continue to expand and destroy much of the organ.

Cellulitis. With some bacterial agents, particularly streptococci, there is no appreciable walling off of the original lesion and the infectious agent dissects along tissue planes. This is especially likely to occur in loose subcutaneous tissues. *See* STREPTOCOCCUS.

Systemic effects of inflammation. Many inflammations may give rise to no discernible generalized reactions. If the inflammation is severe, there may be well recognized signs and symptoms. Fever and increased white blood cell count may be noted even with a localized abscess such as a carbuncle. Generalized abdominal pain may be present in appendicitis because of secondary inflammation of the lining of the abdominal cavity. Enlarged, tender lymph nodes are frequently noted in association with acute tonsillitis. Headache and double vision may be the first sign of a brain abscess. The systemic reaction will depend on location, severity, and character of the inflammatory process, and firm generalizations cannot be made. Individuals with certain hormonal disturbances such as diabetes, or vitamin deficiencies such as in scurvy, are apt to respond poorly to inflammations, particularly infections. Partial immunity to an infectious agent, either through prior exposure or preventive inoculation, may modify the inflammatory reaction considerably. *See* IMMUNITY; INFECTION. [W.S.A.]

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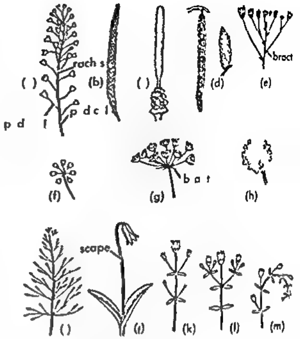
Inflorescence

An inflorescence is a flower cluster or the arrangement of flowers on a plant. It is a branch system—simple if the main axis is undivided, compound if the axis divides into two or more branches. The stalk of the inflorescence is the peduncle, the axis is the rachis, and the stalks of individual flowers of the cluster are pedicels. The inflorescence may be subtended by a whorl of bracts called the involucre.

Types. Inflorescences are classified as determinate when the terminal bud forms a flower, thereby arresting further growth of the axis, with later flowers developing in succession from the tip toward the base, or as indeterminate when the tip continues to grow, forming new flowers in succession, the oldest at base. Indeterminate types include the following: raceme, pedicel of about equal length on an elongated axis; spike, similar to raceme but with sessile (without pedicels) flowers; spadix, a fleshy, thickened spike frequently subtended by a large bract (spathe); catkin (ament), scaly spike, sometimes pendent, of unisexual flowers; corymb, lower pedicels elongated giving flat-topped appearance; umbel, pedicels all arise at top of peduncle and radiate like umbrella ribs;



Inflorescence types. (a) Raceme. (b) Spike. (c) Spadix (pistillate). (d) Catkins, male and female. (e) Corymb. (f) Simple umbel. (g) Compound umbel. (h) Head. (i) Panicle. (j) Solitary. (k) Simple cyme. (l) Compound cyme. (m) Helicoid cyme.

head, rounded or flattened compact cluster of sessile flowers on a very short axis or receptacle; panicle, a branched raceme.

Determinate types include: solitary, lone flower on peduncle; cyme, loose, flat-topped cluster with central flowers opening first; helicoid cyme (often referred to as scorpioid), coiled cluster with flowers on only one side of axis.

Considerable confusion exists regarding the use of the terms helicoid and scorpioid. As the two types are not readily discriminated, some taxonomists prefer to use the older and more common term scorpioid for all coiled inflorescences. *See* FLOWER (BOTANY); PLANT ORGANS. [N.A.]

Bibliography. See PLANT TAXONOMY.

Influenza

An acute respiratory viral infection, usually epidemic in occurrence.

Four immunologic types of influenza virus are known. Group A appears to be subject to continual antigenic changes, group B changes to a lesser degree, and C and D groups seem antigenically stable. The infectious particle, about 100 mμ in diameter, may be inactivated by heat, ultraviolet irradiation, or formaldehyde. Chick embryos are the chief laboratory hosts for study and cultivation (see CULTURE, EMBRYONATED EGG). The viruses are capable of agglutinating red blood cells, from which they then spontaneously dissociate. *See* MYXOVIRUS.

In human infection the virus enters the respiratory tract in airborne droplets; within 1–2 days inflammation of the respiratory tract occurs with

le er ch ll and mu lar ach Asymptomatic nfect n oc u Bact ial compl cati s may p o- d e mo evere ill es es e pe ally pneumo a D agno s by i lati n of irus fr m throat w h gs i n ulat d i t mbryonated egg or by hem gglut n t n h b t ng c mplement fix ng or ut al zing ant body e pon es i bl od *See* COM PLEMENT FIXATION TEST NEUTRALIZI G ANTIBODY

I flue za occ i uc e e epidem c wa es and al in pa dem c Th a t e ic shift f influenza u ually oc ur grad all that t a s wide p ad n ne y r c f ome immunity ag in t th se pre l t in the next eve al y n H wever sudd n wide a t gen c sh ft d ec n the group A ru of th A ian nfl a pand m (1957 1958 how d mark d nt n d ff re c fr m g oup A t i s of pr ced g ye r nd few pe on had p t ct ng t b d e Ep d m c may start with t an p rtat o of r by tra el r a cum l t on of ffi nt umbers of s ept ble and mutat on f the iru

Va cine made up f current v i s grown in embry n t d e g and n cti at d by fo mal n or ultra i let l ht, e f r l ti ely tran i nt re i t an e t rel t d t i *Se* ANIMAL IRUS BIO- LOGICALS [J L M]

Information theory

A b an h f c mm n at n theory dev ted t prob- l m od ng A que fe tu of nf rmat on the ry i it f num al m a ur of th am nt f i f rm t g i ed whe th o te t of a mes ag a e l arned I fo mat on the ry el es he i ly th m th m t l e f p obab l ty F thi r a on th te m f rmati n the ry is f t appl ed l o ly t th r pr b bil t e t des n mm i at theory uch a sig al d t tio nd m n and predict on *S* CO IMUNICA TIONS ELECTRICAL

Inf rm tio the ry p o des im a fo comp r i g d ff r t mm n ati n y tem Th need fo mp r n be me e de t d ng th 1940 A la g r iv l t mat d be s v t d to mak bett of x l ng w t and r dio pe trum al locat (f r mple MODUL ATION RADIO PECTRU I ALLOC TIO S TRANSMISSION THEORY ND METHO S) I th 1920 th p obl m f com pa g t l g ph s tem ttra t d H Nyqu st a d R V L H rtl y wh pro ded some f th ph l sophy beh d i f rm t the ry In 1948 C E Sh n n publ h d p e gen ral tl ry whi h f med th b f ubsequ nt w k nf rm theo y

In nf m t the y mmu t on y t ms mp ed the ba i f gnal g at F d ng pp p i te d fin i n of n l g r t wa tself a p bl m hich Sh nn l ed b the u e f h me u f f rmati n t be expl ed l t Of pec l nte est e ptim l s stems wh h f r a g n e f omm i t n f l t tia n a m x mum gnal g at Opt m l t m pr d mm n ati n y t m d gn w th u e- ful absolute bounds on obta nable signaling rates Although optimal y tems often u e c mplicat d and expens e en oding equipment they provide in ight into the de gn of fa t practical y tem

Communication systems In de igning a one way commun cation sy tem from the tandpoint of i f rmation theory th ee part are con idered be- yo d the contr l of the y tem de gner (1) th ou ce which generate me ages at the tran mit ting end f the y tem (2) the de ti ation which ltimately e ei e th mes ages and (3) the chan nel on ting of a t a m ion med um or device for o eying gn ls from the ource to the de ti nat on Co tra nts b yond the mer phy ical prop- ert e of th tr n mi on medi m infl ence the des g e F r example in de ign ng a radi sy tem nly a g n porti n f th radi frequency sp ec t um m y be va lable t him H s tran m tt r p wer m y als be l mit d If the y tem is ju t o e link in a larger sy tem whi h plans to u e re g ative epe te s the de igner may b restricted t pul t an mis on sch mes All uch conditions a e c n de ed pa t f the de cr pt on of the chan n l Th ur e d not usually p oduce m ag s in a form acceptable as i put by the chann l The tra mitt ng nd f the sy t m conta ns n th r de c called an ncode wh ch p epares the ource me ages for inp t t th ha nel Similarly the re e ng end of the y tem will conta n a dec der to o ert the utp t of the h nnel nt a form re ogn able by the de ti at on The encoder and de der ar th pa t to b de igned In adi sys tems thi de gn is es ent ally the choi e f a modu lat r a d detect r

Dis te and c nti uous cas A source is called d scr te if it me ages are sequences of elements (l tte s) taken fr m an enumerable et of p s bili t (l habet) Thus our e p du ng integ r data or written Engli h r d rete So rc s which are t d sc te r all d co ti uou fo example pe ch nd mu ourc Likewi e hannels re la f ed disc te c ntin ous a c ding t th k nd f i) they t an m t Mo t tr mi on med a (ch as t a mi n l nd rad o path) ca p vide n nt nu u cha nel howe e con str nts (su h a a re tricti n t use p l e te h n qu) n th e n of these m dia may con rt them nto d c et chan els

Noisel ss and no sy es Th output f a ch n n l need ot gr e w th t input For ex mple a ha n l m ght, f ecrecy pu po s ta n a cryptog aph c devic to crambl the me s ge *S e* PRIVACY SYSTEMS (SCRAMBLING) St ll if th outp t f th ha el a b c mp ted k wing j st the i p t me ge the th ch nn l lled no e l s If howe andom ge is m ke th o tput pr d ct ble e en whe th inp t s kn wn then the h n l i c ll d n i y

Encoding and decoding M ny enc d rs fi t break th me s ge to a seque f lementary bl cks next they bstit te fo ea h block a r p- r entati od gn l itabl fo inp t to

the channel. Such encoders are called block encoders. For example, telegraph and teletype systems both use block encoders in which the blocks are individual letters. Entire words form the blocks of some commercial cablegram systems. The operation of a block encoder may be described completely by a function or table showing, for each possible block, the code that represents it.

It is generally impossible for a decoder to reconstruct with certainty a message received via a noisy channel. Suitable encoding, however, may make the noise tolerable. For illustration, consider a channel that transmits pulses of two kinds. It is customary to let binary digits 0 and 1 denote the two kinds of pulse. Suppose the source has only four letters A, B, C, D. One might simply encode each single-letter block into a pair of binary digits (see Code I of table). In that case the decoder would make a mistake every time noise produced an error. If Code II is used, the decoder can at least recognize that a received triple of digits must contain errors if it is one of the triples 001, 010, 100, 111 not listed in the Code II column. Because an error in any one of the three pulses of Code II always produces a triple that is not listed, Code II provides single error detection. Similarly, Code III provides double error detection, because errors in a single pulse or pair of pulses always produce a quintuple that is not listed.

As an alternative, Code III may provide single error correction, an idea due to R. W. Hamming. In this usage, the decoder picks a letter for which Code III agrees with the received quintuple in as many places as possible. If only a single digit is in error, this rule chooses the correct letter. More elaborate lists of codes may be constructed to correct worse errors or to accommodate larger alphabets.

Even when the channel is noiseless, a variety of encoding schemes exists and there is a problem of picking a good one. Of all encodings of English letters into dots and dashes, the Continental Morse encoding is nearly the fastest possible one. It achieves its speed by associating short codes with the most common letters. A noiseless binary channel (capable of transmitting two kinds of pulse 0, 1 of the same duration) provides the following example. Suppose one had to encode English text for this channel. A simple encoding might just use 27 different 5-digit codes to represent word space (denoted by #), A, B, . . . , Z; say # 00000, A 00001, B 00010, C 00011, . . . , Z 11011. The word #CAB would then be encoded into 00000000110000100010. A similar encoding is used in teletype transmission; however, it places a third kind of pulse at the beginning of each code to help the decoder stay in synchronism with the encoder (see TELETYPEWRITER). The 5-digit encoding can be improved by assigning 4-digit codes 0000, 0001, 0010, 0011, 0100 to the five most common letter #, E, T, A, O. There are 22 quintuples of binary digits which do not begin with any of the five 4-digit codes; these may be assigned as codes to the 22 remaining letters. About half the letters of English text are #, E, T, A, or O; thus the new encoding uses an average of only 4.5 digits per letter of message.

Three possible binary codes for 4-letter alphabet

Letter	Code I	Code II	Code III
A	0 0	0 0 0	0 0 0 0 0
B	0 1	0 1 1	0 0 1 1 1
C	1 0	1 0 1	1 1 0 0 1
D	1 1	1 1 0	1 1 1 1 0

More generally, if an alphabet is encoded in single-letter blocks, using $L(i)$ digits for the ith letter, the average number of digits used per letter is

$$L = p(1)L(1) + p(2)L(2) + p(3)L(3) + \cdots \tag{1}$$

where $p(i)$ is the probability of the ith letter. An optimal encoding scheme will minimize L. However, the encoded messages must be decipherable, and this condition puts constraints on the $L(i)$. B. McMillan has shown that the code lengths of decipherable encodings must satisfy

$$2^{-L(1)} + 2^{-L(2)} + 2^{-L(3)} + \cdots \leqq 1 \tag{2}$$

The real numbers $L(1)$, $L(2)$, . . . which minimize L subject to the condition (2) are $L(i) = -\log_2 p(i)$ and the corresponding minimum L is

$$H = -\sum p(i) \log_2 p(i) \tag{3}$$

digits per letter. The $L(i)$ must be integers and $-\log_2 p(i)$ generally are not integers; for this reason there may be no encoding which provides $L = H$. However, Shannon showed that it is always possible to assign codes to letters in such a way that $L \leqq H + 1$. A procedure for constructing an encoding which actually minimizes L has been given by D. A. Huffman. For (27-letter) English text $H = 4.08$ digits per letter, as compared with the actual minimum 4.12 digits per letter obtained by Huffman's procedure.

By encoding in blocks of more than one letter, the average number of digits used per letter may be reduced further. If messages are constructed by picking letters independently with the probabilities $p(1)$, $p(2)$, . . . , then H is found to be the minimum of the average numbers of digits per letter used to encode these messages using longer blocks.

Information content of a message. The information contained in a message unit is defined in terms of the average number of digits required to encode it. Accordingly the information associated with a single letter produced by a discrete source is defined to be the number H. Some other properties of H help to justify using it to measure information. If one of the $p(i)$ equals unity, only one letter appears in the message. Then nothing new is learned by seeing a letter and, indeed, $H = 0$. Second, of all possible ways of assigning probabilities $p(i)$ to an N-letter alphabet, the one which

m xim zes H i $p(1) = p(2) = \quad = 1/N$ Th s ituation s th e ne in which th unkn wn lette seem mo t ncert n therefo e it does em c r r t that learn ng such a letter p o ide the most i f rmat o The orrespond ng maximum alue of H s log N Th s re lt s ems ea nable by th following argument When two independent letter ar le rned the info m t on btained should be $2H = 2 \log N$ Howev r u h pairs of l tter may be onsid red to b the letters of a la g r alph bet of N^2 qu lly likely pairs The nf rmat on as soci ted with o e f these n w lette s is $\log_2 N^2 = 2 \log N$ Alth ugh H gi n by Eq (3) s d men less it s g en un ts called b t (a c ntr cti n of *bi ary d gits*) O onally the inform ti n is x p essed *in d git of oth r kind* (u h as te nary or dec mal) Th n ba es oth r than 2 ar u d f r the lo arithm in Eq (3)

Entr py Most me age s ce do not m rely pi k auc e s e l tt r nd p nd ntly F r example in Engli h H the mo t lik ly lette to f llow T b t *is oth rwi* ot comm n The so r e i im g n d t be and m p oces n which the letter p bab lities cha ge d pe di g on what the pa t of the m s age has bee Stati ti al co r lat ns *betwe* d ffe nt part of th me age may be x pl ted by encod ng longe block Th a e age mb r of d git per l tter m y the eby be red ced bel w the gi l tte nf rmat on H g ven by Eq (3) F r exampl by n cod ng E gl h word i st ad { ngl l tt r 1 d g ts/l tter fi e En cod ng lo g a d l ge block th number of dig t *needed* pe l tte appr hes a l miting m m m valu Thi l m t is call d th ent py f th sourc and i int preted a th rate b t pe lett at wh h the sou ce gen *rates* inf rmati n If the r e produ e lette t m f xed a e g rate l tt r / ec, the tropy may also b on *verted nt a at* n b t per sec nd by m ltipl ng by *n* Th ntropy may be mp t d fr m table gi ng th p b bil t s of block f N letters (N gr m) If n Eq (3) the mm t on index i s e t d d o n ll N gram then th n mber H repre e ts th nf rmat N ecut ve l tte A $N \to \infty$ H/N app ch th e t py of the *ou e* Th e t p f E gl h h be n e t mated b Sh nn r be b ut 1 b t/l tte H we an en ode m ght ha t ncod 100-gram o der t a h a ed t t n ar l d g t/lette Compar g Engli h with a u e wh ch p odu es qu lly l kely l tt r dep nde tly (nd h nc has nt p l g $7 = 4.8$ b t l tt) th e lt i l t n estat d E gli h 80 r d ndant Othe mm n n es l ry ed dant Fac im il f mpl a be peeded by a fa t of 10 by m f p t le od g te hn que

Capacity Th t n f ntr p m w d ly ppl bl than m ght ppe fr m th di cu n f th b nary ha l A y d scr te n el han l m y be gi n n mber C wh h lled th pa ty C d fined a th ma m m t (l t pe eco d) f ll sou e th t m y be nne ted d ectly t th l) Sha n p d th t ny gi n s urce (whi h perhaps can ot be connected d rectly to the chann l) of entropy H bits/letter ca be ncoded for the channel and run at rates arb tra ily clo e to C/H lette s/ ec

By u ing rep titi n error correcting codes or similar te hniqu s th rel ab l ty of tran mi si n o r a no sy chann l can be increased at the ex pe f l wing down the source It might be ex pected that the our e rat mu t b lowed to 0 bits/second a th transmi s on is required to be m ea ingly err r free On the c ntrary Shannon pr ed that even a no sy han el has a capa ity C Supp e that rr n in at mo t a fr ction of the letters f the me sage ca be tolerated (> 0) Suppo e l that a gi en s urce of entropy H b t /lett r mu t be op ated at the rate of at lea t $(C/H) - \delta$ letters/ ec ($\delta > 0$) No matter how sm ll ϵ and δ are cho en an e coder can be found wh h s t sfie these requ reme ts

For xampl the ymmetri binary h nnel has t nary i put and u tput lett r no n changes a fr ct o p of th 0s to 1 and a f a ti n p f the 1s to 0 and t n its suc n n digits independently The apacity of th s chan el i

$$C = m(1 + p \log_2 p + (1 - p) \log (1 - p))$$

where m i the n mber of d g ts pe econd which the han el t n mit

A f mo s formula

$$C = W \log_2\left(1 + \frac{S}{N}\right) \tag{4}$$

gi es th apac ty C f a band l m ted c nt n ou ch nnel The cha n l con i ts of a fr quency l a d W cycles pe e ond w de c nt in ng Ga i ian noi f power N The noi e has flat sp ctr m ov r th b nd a d i added to th s gnal by the *channel The hann l al* cont i s a tr i n that the a ag gn l pow r may not ex ed S

Equ t on (4) llu trat an xchange elation sh p betw en bandwidth W d l to-no n atio S/N By s table en di g s gnal ng y t m can u a m ll bandw dth pro ded th t the sign l pow r i also ra ed en gh t k p C fi ed See B NDWIDTH REQUIREMENTS (COMMUNICATIONS)

Typi al ap c t l es re 0 000 b ts/ ec f r t leph n peech ct u t d 50 000 000 b t / ec f r a b o dcast t le i on ci u t Speech nd TV a e v ry edu da t and wo ld u e hann l of mu h lowe capa ity f the n ces ry ncod ngs wer inexpen For ampl the ode can end sp h o l sl ghtly di torted o 2000-b t / ec h nn l (s e VOCODER) Succ ve li es o f ames t l si n t nd to look alike Thi re- mblan ugge ts a h gh r d d ncy howev t xplo t t the n der m y ha t encode in very l g blocks.

N t all f th wa te in chan l ap city an b ttr buted to so r e red dan e Even w th red dant so r su h a ource pr d i g r d m d git some channel cap city will be wa ted Th mpl t e d g h m p ovid r l able t an m i n ly at a ate qual t th capacity f

a channel with roughly 8 db smaller signal power (the 8 db figure is merely typical and really depends on the reliability requirements) Again more efficient encoding to combat noise generally requires larger sized blocks This is to be expected The signal is separated from the noise on the basis of differences between the signal s statistical properties and those of noise The block size must be large enough to supply the decoder with enough data to draw statistically significant conclusions *See* NOISE ELECTRICAL [E N G]

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Information theory (biological applications)

Information is customarily analyzed with respect to meaning origin and value The modern information theory adds another dimension amount The need for a measure of amounts of information arose in telecommunication and in the general treatment of control and communication (cybernetics) Once a precise technical definition had been developed it was found that its domain of validity was wide and included biology *See* BIOLOGY CYBERNETICS

Representation theorem The first basic concept in information theory is that the information content of an event is not defined by what has occurred but only with respect to what might have occurred instead For instance the amount of information in the phrase 4 miles per hour is defined only against a background of other possible speeds To formalize this idea consider the set of all actualities (things processes) which may be relevant in a given class of situations let these actualities be partitioned into classes according to any principle chosen these classes together form a pattern of information about the actualities under consideration Amount of information is not defined with respect to the actualities themselves but with respect to a given pattern of information about them It is related to the task of specifying (selecting recognizing) a particular class in a particular pattern for a particular actuality

The information contents of two different patterns are compared by determining whether one can represent the other If every class in a pattern A can be associated with at least one class in a pattern B then every event as defined under pattern A can be represented by some event defined under pattern B and B is said to have an information content at least as great as A The comparison is merely formal it makes no difference whether the association invoked is natural or arbitrary and whether or not a representation of A by B is likely to occur A common yardstick for all patterns of information is obtained by using a standard representation it is customary to use binary symbol In other words the information content of a pattern X is determined by finding how many yes-or-no decisions are needed on average to specify which particular class of the pattern has occurred As in a botanical key the number of decisions made is not necessarily the same for all classes it will be efficient to associate events which occur frequently with the shortest decision sequences (as in the Morse code in which the shortest symbol groups are used for the most frequent letters) It is shown in texts on information theory that the optimum relation is achieved if each class of probability p is represented by a binary number of $-\log p$ digits In general it will be necessary to set up the representation for N sized clusters of events in order to obtain a classification in which all probabilities p are integral powers of ½ Therefore if X is a pattern of information comprising r classes with probabilities p_i (where $i = 1\ 2\ \ldots\ r$) there exists a function $H(X)$ which is the minimum average number of binary symbol per event its value is given by

$$H(X) = \sum p\,(-\log_2 p)$$

$H(X)$ can be as small as 0 (when one $p_i = 1\,0$) and as large as $\log_2 r$ (when all ps are equal) It is called information content (amount quantity of information) of X and also the uncertainty of X (some prefer opposite sign for these two functions) It is also called entropy (or negentropy) because it is related to physical entropy the term measure of specificity can be used to avoid the association with mental processes implied by the word information *See* ENTROPY

The H function is important in dealing with transfer of information Any operation on information involves mapping from one pattern A into another pattern B In many instances the patterns are very dissimilar and the transfer operation far from perspicuous The following theorem holds for every act of information transfer transfer from pattern A into pattern B is possible only if $H(B) \geqq H(A)$ and the amount of information transferred per act cannot be greater than $H(A)$ This is the content of the representation theorem the first fundamental theorem of information theory It importance is that it can be used to check the possibility of an operation It does not imply that such an operation actually occurs it says nothing about the mechanism of information transfer and particularly it does not imply that efficient binary coding is used at any stage of the process it says nothing about cause and effect of the

perat n and ther fo e applies ju t as well to r sc ous c mmun cat a t th t an f r of gen t pec fi at n f om par nt to ffsp ing

B c u nf rmati al bookk ping ca b applied t a y f rm of inte acti n the rep esentati n theo em p o ides a u ful c t n wh h any f p d mecha i m mu t t fy If pa t *A* of a sy tem is ppo d t c ntr l part *B* then it m t be a med that p t *A* ca m t at le t s many diff t c t ol gn ls as the e ar diff r nt c n t lled respo e n *B* If *A* supp sed to main tai hom t of *B* then the effe ti e r ty of c tr l g al em tted by *A* m t match th riety of ff ct wh h t d to mo e *B* aw y f om t fix d v lue Sp c fic ty f p ing f hormo n with ta g t rg e zyme w th s bstrate and ant g ns with t b d e n the b e of di e ted c mmu c t mpl th t the pe ific at on of o e rea tion p rt m ll be omeh w in ribed pon the th r If the choi e of 1 ami o a id t of 20 t be spe fied by el t r of nucleot d s take f m s t f 4 the el t r of 2 s n suffi ie t be u t yi lds only 16 c mb n tion nd a lu te of 3 yi ld 64 whi h i m e tha eded mu h ffo t h b en pe t s far with ut success to t bl h a d t t a y t m of orre p nden e betwe the tw k nds f m l cules *S* AMI O ACIDS

One m ght expect t find nfo mat nal l k keep ng m t ewa d g n deal ng with t m lu pe pt n nd re pon How e tl t nly f th p pl eral part f the p es I forms t m nali h lpf l n mapp ng st mul pr p t n e e tg n te p es nd n ry s ig al nd in m pp m sel a tion up n erve ig l It lso y lds t fa t ry lts in n lyzing th r all pe forms f the rga i m Howe r it ha so fa bee mpl tely a leq t in d aling with the e t l n y t m In om g ig al d pp i to and r p n es s e o t f sy tem th t rd r f mag t de mo compl x t stru t a d fu t n th n ca l e a c t d fo i any impl fa hi It sp t d that entr l operati ns occ n h ghly mpl t t st e l fa hi n h h w ld et s tate m h el me tary i f rm t t affi t a h e en c mpar t ely mpl lt with h gh reli b l ty

Noise and redundancy *theorem* The elati between r l bil ty a d *inf* m t n c nt nt n titutes th sec nd b a perr of nf rm t on theory Con d nf m t n tr fer fr m X nto Y f r ampl l t *Y be the input* a d *Y* the tp t f some yst m If sch tr sf r p oc s s pe fectly el abl th n k wing X imple k w g l n d y ce rs *X* nd *Y* r d to be n ct d by n seles cha nel nd $H(X) = H(Y)$ If th t a f p oces is bj t t pertu bat th t s f the ch nn l noi y th s m nf ma t n w ll b l *t in t* it and th re will be m rt ty n g Y f Y kn wn Thi un rt nty i call d equ ocat n nd d g ted $H(X/Y)$ Th d ff e u cert nty ernu g Y *before* a d after the tran fer process that is $H(Y) - H(Y/Y)$ is c lled th amount of infor mati n *transmitted*

If c nt ol act on depends upon inform t on transm tted th n input eq ivoc t on will sometimes le d t faulty re po e The only prot ction ag inst lo s of information is th i corpo ation into the input f extra inf rm t on which can be u ed to sp t and correct error This is redundant in form tion A t i ial e ample of redundancy is the repet tio of a me s ge I gen r l the probabil ty of a error remain ng uncorrected will be small r the more red ndant informat on is added and the m re efficie tly it used It is h wn in texts on informati n theory that it is po ible to make the er o probab l ty anish by prec ly mat h ng the amo nt of redundant informat on to the amount of nform t n wh h s expect d t b *lost* as a *result* of no se This is the co tent of th no se and redundancy theorem the sec nd fundam ntal theorem in inform t on theory

Although t i alway p ssible to elimi ate errors it i often ot p actical and ind ed not efficient It h s been s e ted that an opt mum strategy for li ing th nga s to c mmit as many errors as is mpatibl with survival (Dan off's principl) Th s ha been u ed t e tablish relations between the p obab l ty of an o gan sm to fail (f r example death rat) and am unt of wear a d tear it s bject d to the course of ord nary aging o as a result of the dm n tr tion of a ou delete us g nt *S e* INFORMATION THEORY [R O]

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Infrared detector

A devic fo detecting electrom gnetic adiat on h ing a wa el th greate than th t detectable by th human e *S e* INFRARED RADIATION

I f r d det ct rs are used n elect on c equipme t for ma y pu pos s s cl as det cting fi es detect g o heat n in m ch nery dete ting pl e eh les nd eve people nd cont oll g t mperature sen ti e ind trial p oce ses

Inf red detect rs may be l s fied by the b si mech n m of *op* tion On clas called *thermal* det ctors u es the powe f the rad at on to in r a e the temp ratu e of the det t g l m nt. *This in tur* ca ses some pr perty of the detect often the ele t al re stan e t cha ge In the *eco d cla* lled ph tod t ct s the r di tion p od es a d ect ffect som lect i l property f the d tector

The therm l cl ss c mp ises the rad at o ther moc uple th bol m t nd the G l y cell The rad at o the moc pl h s *numbe* of thermocouples n ect d in ser ar nged *that the*

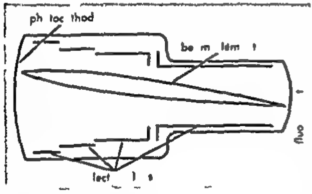
radiation falls on half of the junctions thus causing a voltage to be generated The bolometer functions through a resistance change in a material having a high temperature coefficient of resistance The Golay cell utilizes the heat of the radiation to deflect a diaphragm in accordance with the amount of radiation *See* BOLOMETER THERMOCOUPLE

The photodetectors can be classified by type of most efficient use as photoconductive and photovoltaic These in turn can be classified into the compound types such as lead sulfide lead selenide lead telluride and thallium sulfide and the elemental types such as germanium and silicon However some types such as germanium or silicon photodiodes and phototransistors can be used as either photoconductive or photovoltaic detectors For more detailed information *see* PHOTOCONDUCTIVE CELL PHOTODIODE PHOTOTRANSISTOR PHOTOVOLTAIC CELL RADIOMETRY [W R SI]

Infrared image converter tube

A tube which effectively allows one to see in the dark It was developed during World War II in response to an obvious need for such a device

The infrared image converter tube or the infrared telescope as it is sometimes called is an evacuated tube which has on one end a transparent



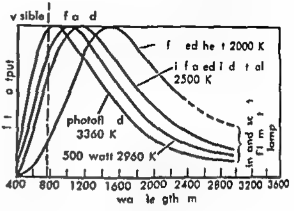
Infrared image converter tube

photocathode sensitive to infrared radiation The scene to be viewed is optically focused on this photocathode causing electrons to be emitted in proportion to the intensity of the infrared illumination The electrons so emitted are focused by electrostatic lenses upon a fluorescent screen at the other end of the tube which is excited by electrons impact into radiating visible light and thus gives a visible image of the invisible excitation at the other end of the tube The basic structure involved is shown in the illustration Such tubes are sensitive out to 1 2 μ The visible spectrum extends only to 0 7 μ

The infrared image tube by itself is not sensitive enough to see any but rather warm objects such as a hot engine or a lighted cigarette As a result it is necessary to use an infrared searchlight to illuminate the field to be viewed With such an arrangement systems were made which had a range of as much as 100 yd *See* INFRARED RADIATION VACUUM TUBE [K R S]

Infrared lamp

An electric lamp that radiates energy at wavelengths between 760 and 5000 millimicrons (mμ) in the electromagnetic spectrum Infrared lamps



Spectral distribution of energy from various infrared sources (From Illuminating Engineering Society IES Lighting Handbook 2d ed 1952)

are essentially incandescent lamps operating at a reduced voltage with a filament temperature of 4000 F Between 10 and 15% of the energy is converted to light Both carbon and tungsten filaments are used the tungsten is more efficient The average life is 5000 hr and 25 different types are available Other forms of radiant heaters generate longer wavelengths causing heat absorption by the air The short waves generated by the infrared lamp can be concentrated and directed the reflector type lamp is the most satisfactory The illustration shows the spectral distribution of energy from various incandescent filament lamps The infrared lamps concentrate their energy in the infrared region

Infrared lamps are used for therapeutic treatment for heating applications in industry and in homes and for farm use in brooders (called heat lamps) They are effective and safe and the heating effect is instantaneous because the air need not be heated first The most extensive applications is in industry where they are used for baking (such as the curing of applied finishes) for heating (as in preparing material for processing) and for drying (as evaporating liquids) *See* INFRARED RADIATION INFRARED RADIATION (BIOLOGY) SPECTROPHOTOMETRIC ANALYSIS [J O K]

Bibliography Illuminating Engineering Society *IES Lighting Handbook* 2d ed 1952

Infrared radiation

Electromagnetic radiation whose wavelength lies in the range from about 0 8 micron to about 1000 microns (1 mm) The lower of these limits is determined by the long wavelength limit of the human eye sensitivity to red light and the upper by the shortest wavelength limit to radiation which can be generated and measured by microwave electronic devices All solid bodies whose temperature is above abso-

lute ze o adi t som er y n the inf ared and if th effect temperatu e h a val ie up to about 3500 K the ad ation fall prepo de antly i the inf a ed He e inf ar d radiat n is ft n e ll d h at rad ti r heat rays

Th f ared n w d c red abo t 1800 b Sir Will am H r chel He fou d th t unli ht di per ed i to a p t um by a gla s pri m howed it ate the t ng effect o t ide th v ble part f the spe trum just beyo d the r d end Her hel n l d d th t th ff t wa due to i vi ble r dia t of the s m n tu e as light pt f r it in ab l ty t affe t th In the e t 50 years ex perimental p oof f thi i w sl wly accumulat d nd t h s b e g er lly a c pted l y ci nt ts for th pa t entu y

Am ng th sc ent fic ndi trial and m l tary appl cat n of infr r d adi t o the may be m nt ned q l tat and quantitat chemi al a aly by fr ed pe t o py ont ol of in d trial proc se ad ant h at ng nvi ble g al i g f bu gla al rms mil tary mes ages d the l ke active d p detect n of m litary targ t and m ile g dan

Thi rt le di c sse the pe t al s bd i on so r e dete t and p gation f nfr red d at n F related a d ppl m ntary nforma t n ELECTROMAGNETIC RADIATION HEAT RADIATION INFRARED LAMP INFRARED RADIATION (BIOLOGY) INFRARED SPECTROSCOPY MISSILE GUIDANCE SYSTEMS PHOTOGRAPHY RADIOMETRY SPECTROPHOTOMETRIC ANALYSIS

Infrared spectrum The inf a ed eg n is often l di ded b t th e s no r l g eem nt abo t the n mes nd bou da i s f the bd i Th a ompanyi g t bl g e a ubd wh h i based o t m tal h a tern t b t which also rresp nds i ugh way t th ubd v ion f n t l f q nc f m le les a h wn n the la t lum Th bo d e f the s bd i s a e th arb t a v a d ppr m t

A th table impli e t inf a d d at n e n be d tected by ph toelect c lls and t c rre spo d i f equ ncy nge to the l wer n rgy l v l f le tr n n mole ule d m ondu t r (the high lect n c l v l orr sp nd of o r t th f qu n es f bl a d lt iol t radia t n) Th t rmed at f ed r g n e e the f q n y r ng f mo t m le l r v b ati n nly th rt n s of th h gher v b at al fr quenc

Subdivi ions of the infrared pectrum

W l gth range	W mber ran cm	N mes used	Appropriat m lec l m ns
[illegible] 5	4000–1 500	N IR ph toelec t IR	Low lectro l l bra t l
5–50	00–4000	I t rmed t IR	to ea M lecul frat
0–1000	10– 00	Fa IR gra IR	M lecul rot tio

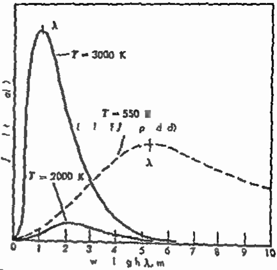


Fig 1 Spect l d t b t o f d t inte ty J f om n c nd sce t bl ck b dy (th te m appl d t th t lly p rf ct rad t) at temp t T Th d t J s th d t p w r i w H p u n it of d ngl pe tim t of w v l gth t λ l th fi t m l wo f gth ge d

f ll out d it Th s reg n i omet m s called the p sm infr red b u e pectromet rs equ pped with alkal halide pr ms r c nmonly u ed l ere The far inf a d whe diffraction grati gs mu t b used i p ctromete because s itabl pr m m ter als a e kn wn pa the r gion of v ry low molecula b at n l f eq encie nd m t ota ti al freq en ies t lea t of th l ghte mol cul s Be a se rad ation of abo t 1 mm wa el ngth the uppe limit et f r the far i f ared n al o be pr du ed nd detected by m c ow ve rad r devic s th e i n gap b tw n the nfr red nd mic wa dom in d n fa t the reg on n th side of 1 mm i unde inv st at n b bo h te hn q e S MICROWAVE

Sources of infrared radiation The u ual sourc f i fra d r diat n an ncande cent sol d body S ch s u ces produ e o t nuou bro d ra ge of wa l ngths The d t ibut f diant energy am g th wa ele gths mitt d by a ol d b dy o di a ly ha the f rm h n n Fig 1 with a pr noun ed maximum at some wa el ngth λ_{max} a athe harp d crea e on the l w wavel ngth s d d a ge tler sl pe at l g wa l gth

I f ared r di tion may be m tted by syst m th r tl a h t bod n app x mate internal the modyn m equil bri m, as f e mple b g e th u h wh ch an lectr c l d ha ge i pa d S ch sy t m a not elle ti e mitte s nd eld m n d s i f ar d sources At present no y i kn wn f produ i g m ochr mat in fr red ad at on wh n s h rad at on is wanted t bta ned by a suitable proced re f lat ng t f on a e nt ou d tribution of nf a d wa e l ngth s h a th t h wn in F g 1

Detectors of infrared radiation Detectors of le t om gn t r d tion ma b t f d b oadly

into quantum detectors resonant detectors and heat engines or thermal detectors The fir t are devices which convert a quantum of the radiation in question into a proportionate signal by some process which is in ensitive to quanta of less than a certain energy (for example the mean energy of quanta emitted by a body at room temperature) Photographic emulsions photoelectric cells and Geiger counters are examples of quantum detectors Re onant detectors are devices that are responsive only to radiation of the frequency to which they are tuned Heat engines act as detectors by con verting the radiation into heat and using the heat to operate a device that produces a signal that is pro portionate to the amount of radiant energy re ceived

No resonant detectors have yet been constructed which can be tuned to infrared frequencies For the photoelectric infrared (see the table) quantum detectors in the form of pecially sensitized photo graphic emulsions photoemissive cells and par ticularly photoconductive cells are usable As can be seen from Fig 2 the responsivity of such detec tors varies con iderably with frequency and drops to low values at wave numl ers of al out 2000–3000 cm ¹ (3 5–5 μ in wavelength) Photoconductive detectors are known having good respon ivity l e low 2000 cm (above 5 μ) but these must be op erated at or near liquid helium temperatures (<10 K)

Therefore in a large part of the infrared region heat engine detectors who e respon ivity is the ame to all kinds of radiation provided the radiation is converted entirely to heat in the detector are the

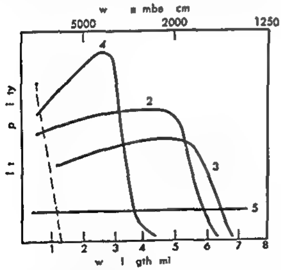


Fig 2 Spectral sensit ty of inf ed d tector 1 Inf a ed sens t zed photog aphic em ls n; 2 PbTe (lead tellur de) photoco d ct e detect (efrig r at d); 3 PbSe (lead sele d) ph toconduct e d tector (refr ger ted); 4 PbS (lead s lfde) photo o d ct e detecto 5 thermal d tect r Respo si ty scale i ot the same for th a ous det ct rs b t the app o mate wa ele gths at wh ch det cto 1 2 3 a d 4 b come le s respo n e tha a th mal d te to a co ectly show

only generally u able kind Examples of heat engine detectors are thermocouples and thermo piles which produce an emf when heated bolom eters which change their electrical re i tance when heated and pneumatic radiometer in which heat is detected by the increase in pressure of a heated gas Because these devices are all subject to the laws of thermodynamics governing the conver i n *of heat into u eful work (that i into a ignal)* their ultimate responsivity is expected to be ap proximately the same and this is found to be the ca e Thermal detectors operating at room tempera ture have a lower limit of ensitivity of the order of 10 ¹⁰ watt with re pon e times of the order of 0 1 sec This limit can be con iderably reduced if the detector is capable of operation at low tempera ture

Propagation of infrared radiation The proper ties of various media for the transmi sion of in frared radiation are often quite different from those of light For example window glass is quite *opaque to 5 μ radiation* whereas pure germanium crystals which do not transmit vi ible radiation are very tran parent to this wavelength (apart from reflection losses which can l e reduced by ur face coatings)

The attenuation of infrared radiation by the atmosphere is of special interest Nitrogen oxygen and the rare ga es are transparent to all infrared wavelengths but water vapor and carbon dioxide are strongly absorbing in certain region In the range 0 8–4 0 μ there is irregular al orption due mainly to water vapor with more or le s open windows at al out 1 0 1 4 1 (2 2 and 3 4 4 0 μ From 4 to 8 μ water vapor and carb n dioxide together are strongly absorbing l ut there i an extensive window from 8 to 13 5 μ This window i of great meteorological importance l ecau e the peak of the radiation curve of the earth falls near 10 μ Beyond 14 out to 600 μ there is more or le s continuous al orption l y atmospheric water vapor arising from the rotational energy level of thi molecule

Liquid water is rather generally opaque in the infrared al ove 2 μ in path length larger than 1 mm The tran mi ion of infrared ra liation tl rougl fog is little better than that f vi il le light l ecau e of a combination of cattering and al orption by the water dr pl t Th *p pular mi c nception* tl at fog is tran par nt t infrared radiati n has p r haps ari n fr m the well ad erti ed effects ene of red en iti e ph t graphic f lm f r ph t graphy tl rough atm pl eric l az of lu t particle

[R C L]

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Infrared radiation (biology)

Inf ared radiat on occupy the pan between the vi ible spectrum and rad o wa es encompa s ng w vele gths 7800–4 000 000 A ne ther boundary be g p e elv d l mited All bod es abo e absolute zer t mper tur a p te ti l sourc of nf a ed rad at the ef e all rgani ms are cont nually e p ed t th m Ab ut 60°' f the r ys e i fra ed Water ab orbs nf ared rad t str gly except for th ba d of trans p re b tw en 7800 d 14 000 A Sin e protopl m c nta n m ch wate it ab o bs nf ared r d t read ly A larg a m l h rbs i fr red d at on t it urf c nly the p n fr m 7800 t 14 000 A penetrati g s la as the blood ves els S INFR RED RADIATIO

Wh le m ny b t n and eve tis es selec t vely absorb nf a ed ray nd e might there f) e po t late s l ct e effect of the e rad ati n n ha e be nequ o ally dem nstrated exc pt po bly n onjunct n with x ray The rea on is pe hap be a q nta of nfr r d rad ati n do not e ite ene gy t tes t m le ules th r than thos exc ted b o d cted h at S e X RAY(S) PHY ICAL NATURE OF

The e e t al b olog c l effect of infra ed rays d pe d p ima ily p n the r e t tempe at re produ ed f ll wi g the ab rption wh h i turn t e es th t f b log al ct tie p por t on to th t mpe atu l ange Becau e of the pr m n e of nf d nlight, rg m h w m y adaptat to d pate r to d th heat. Th t mp r of a l rg a smal o pla t may ri t mpo rily but the h t i di pated by t an p at the pla t a d by pe pirat on in th a mal S bm g d an m l and pla ts ar pr tected by the w te the tempe at re ha ge of wh h depe d pon the h at apacity f the pa t l r body f wat

Tr tm nt f bi l g l m terial with nfr red d t n (800–11,500 A) e the b f re or ft x ray t tm t r se th tr ng me t in h m som nd ed by th ay i t es f pl t d a mal te ted Th wa t wh h the nf a ed r d t do th s i known b t c m p abl am t f co d t d he t does not ha th m ffect

Th m di l m n mak e of nf a ed d a t t tr t p t tra b r t r pher l a c l d se se th ti mu l d m ny th pa n r hi h h at ng gi el f p obably her f nd l t f per ph al v l F r th p rpo gl w l ad t r generally em pl yed but f som p pu es the m e pen tr t g d t n (7800–14 000 A) bta n bl f om n ndesc nt so a e p ferable to the gl w l t mulat ul t d p n the t ue

B H Y S THERMOTHERA Y [A C GI]

Bibl g ph O Cl e M d al Phy s l l 1944 A H lla d (d) R d t B l gy 1 1 19 1

Infrared spectroscopy

The tudy f the propertie of materi l sy tem by me ns f the r interact on w th infrared rad ation d spersed i t a p ct um (*see* INFRARED RADIATION) The i fr red reg on i valuable for tudy of the tr ctu e of matter l ecau the natural ibra t onal freq r c e of atom in m lecules and rys tal fall in the infrared range Some ga ous mole cules also have r tational frequen i s in the f r infrar d an e and c rta n frequenci s corre p n l ing to en gy l v ls of electr ns in sol d and larg m lecules c rre p nd to tho e of the n ar nfr red Fo d ta led di cu i n of molecular v bration and r tat on se MOLECULAR STRUCTURE AND SPECTRA

The infrared bso ption pectr m f a molecule s h ghly chara t r t c and often has been re f rred t as a *molecular finger pr nt* The pe t um n thu be u ed for molecular dentif cat on Be c u e the b o pt on of radiation at v rious in frared f equ n ies s q ant t ti ely related to the numbe of ab o bing m lec les in a sy tem quanti tati e analy i i al o p s ble

Th usefulnes f n i fr red ab rpti n pe trum f de t fi ati n and chemi al analy s was cogn z d s long ag as 1890 In the early 1900 the American phy c t W W Cobl ntz determ ned the infr red spectra of h ndreds of substa ces and learly dem n trated the p tenti l alue of such pectra U fortunately the in trun ent t n f th t d y a cumber m and nece ar ly h memad o that few phy ici ts and ch mi t w e attracted by Coblentz s w k Only aft r the development of c mme i l el ct n c d i es for mpl ficat o and r o d ng of a ont nuou ly sc nn d pectr m was ext n e u e made of th tech que Apart from refi em nt in in tr me tati n th infrared spect a f m le l a e olt i d t d y in ba ic lly the am w y as th t u ed b Coblentz.

Instrumentation and techniques The usual r ng m nt f r mea ur me t of an nfra ed pec trum i hown ch mat all in F g 1 A ou c Q e ds a beam of co t n us nf a d radi t n to sphe al nd n ng m rr r C wh ch p sses the be m through S th sampl to b studi d Som f the i f ared fr quen i s i the beam a ab rb d tr gly me w kly Th r d e d b am pa e and com t f us at th ent nce lit of th mo hr m t r M The latte an inf red spe t mete wh h d spe s the radiation into a p trum One fr quency t a t me ppears at the ex t l t f M fr m wh h th d t n of that f equ ncy is p ed b a su table opt c l y t m to th d tect T Th d te t r (a therm oupl other de) co rt the rad ant energy into a electri al signal whi h i amplified electr lly t A nd re rd d by ch rt order CR

An i f a d pectrum s a reco d f ntensity of inf a d rad at on a a f n ti n of f equ ncy o w length T p oduc su h a r d the ch rt de d en in sy h ni m with th di

into quantum detectors, resonant detectors, and heat engines or thermal detectors. The first are devices which convert a quantum of the radiation in question into a proportionate signal by some process which is insensitive to quanta of less than a certain energy (for example, the mean energy of quanta emitted by a body at room temperature). Photographic emulsions, photoelectric cells, and Geiger counters are examples of quantum detectors. Resonant detectors are devices that are responsive only to radiation of the frequency to which they are tuned. Heat engines act as detectors by converting the radiation into heat and using the heat to operate a device that produces a signal that is proportionate to the amount of radiant energy received.

No resonant detectors have yet been constructed which can be tuned to infrared frequencies. For the photoelectric infrared (see the table), quantum detectors in the form of specially sensitized photographic emulsions, photoemissive cells, and particularly photoconductive cells are usable. As can be seen from Fig. 2, the responsivity of such detectors varies considerably with frequency and drops to low values at wave numbers of about 2000–3000 cm (3.5–5 μ in wavelength). Photoconductive detectors are known having good responsivity below 2000 cm (above 5 μ), but these must be operated at or near liquid helium temperatures (<10 K).

Therefore, in a large part of the infrared region heat engine detectors, whose responsivity is the same to all kinds of radiation provided the radiation is converted entirely to heat in the detector, are the only generally usable kind. Examples of heat engine detectors are thermocouples and thermopiles, which produce an emf when heated; bolometers, which change their electrical resistance when heated; and pneumatic radiometers, in which heat is detected by the increase in pressure of a heated gas. Because these devices are all subject to the laws of thermodynamics governing the conversion of heat into useful work (that is, into a signal), their ultimate responsivity is expected to be approximately the same, and this is found to be the case. Thermal detectors operating at room temperature have a lower limit of sensitivity of the order of 10^{-10} watt with response times of the order of 0.1 sec. This limit can be considerably reduced if the detector is capable of operation at low temperature.

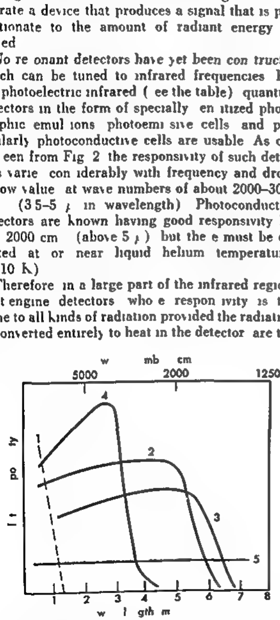

Fig. 2. Spectral sensitivity of infrared detectors: 1. Infrared sensitized photographic emulsion. 2. PbTe (lead telluride) photoconductive detector (refrigerated). 3. PbS (lead selenide) photoconductive detector (refrigerated). 4. PbS (lead sulfide) photoconductive detector. 5. thermal detector. Responsivity scale is the same for the various detectors, but the apparent wavelengths at which detectors 1, 2, 3, and 4 become less responsive than a thermal detector are correctly shown.

Propagation of infrared radiation. The properties of various media for the transmission of infrared radiation are often quite different from those of light. For example, window glass is quite opaque to 5 μ radiation, whereas pure germanium crystals, which do not transmit visible radiation, are very transparent to this wavelength (apart from reflection losses, which can be reduced by surface coatings).

The attenuation of infrared radiation by the atmosphere is of special interest. Nitrogen, oxygen, and the rare gases are transparent to all infrared wavelengths, but water vapor and carbon dioxide are strongly absorbing in certain regions. In the range 0.8–4.0 μ there is irregular absorption due mainly to water vapor, with more or less open windows at about 1.0, 1.4, 1.6, 2.2, and 3.4–4.0 μ. From 4 to 8 μ water vapor and carbon dioxide together are strongly absorbing, but there is an extensive window from 8 to 13.5 μ. This window is of great meteorological importance because the peak of the radiation curve of the earth falls near 10 μ. Beyond 14 out to 600 μ there is more or less continuous absorption by atmospheric water vapor arising from the rotational energy levels of this molecule.

Liquid water is rather generally opaque in the infrared above 2 μ in path length larger than 1 mm. The transmission of infrared radiation through fog is little better than that of visible light because of a combination of scattering and absorption by the water droplets. The popular misconception that fog is transparent to infrared radiation has perhaps arisen from the well advertised effectiveness of red-sensitive photographic film for photography through atmospheric haze of dust particles.

[R.C.L.]

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Infrared radiation (biology)

Infr red rad at ons or py th sp n between the v bl spect um and rad waves ncompa ing w vel ngths 7800–4 000 000 A neitl er boundary be g prec ely delim ted All bod es abo e bso- l te zer in t mper tu e r pot ntial u ces of i f a ed rad at n th ref re ll organi m ar e ntin ally xpo ed to them About 60% f the su r ys a infra ed Water ab orb infrared radiat on tr ngly except f the band of trans- pa ncy betwee 800 d 14 000 A S nce p oto- pla m nt much wat r u ab orbs nf ared d at ead ly A la ge a mal ab o ls infrar d ad ati n at t s rf ce only the p fr m 7800 t 14 000 A pe trat ng as far s th bl od ssels S INFRAR D RADIATION

Wh le m y sub ta ces and even ti u l c t ly abso b frared r y and e m gl t the e- f e po t iate f t ffects f the e r diat n n n h e been un q ocally dem nstr ted e c pt po ibly njun t on w th x r y The r a o is perh p be au e q anta f nfr red r d ti n do n t exc te e e gy t tes n m lecul s oth r than thos e c ted by cond t d he t S e X RAY(S) PHYSICAL N TURE OF

The e enti l bi log al ffect of i f ared ays d p nd p mar ly po the r e i tempe t re p od ed f ll wi g the ab o pt on wh h n t rn e se th rate f b l g cal ct ti s n pr p t t the temp tu e hange B u e of the p m e of nfra d n light rg ms sh w many d ptati s t d ip te t a d th h at The tempe t r f a l rg a mal plant may r se temp ar ly b t th heat i d ip ted by tr p t n th pl t and by pe p rat n n th n m l S bme ged n m l and plant a p tected by the wat the tempe ature h nge of wh h d pe d po the he t apac ty f the par t l body f wate

T eatm t f bi l g al m terial w th i f red ad t (800–11 500 A) the befor r ft r s a t atment ea es th a g me t n h m m du ed b the y in ti es f pla t a d a im l tested Th w y n wh h the i f ed r d t n d th r u kn w b t a m pa al l m t f r du ted he t doe t ha e th m ffect

Th med l ma mak f fr ed d r t t t p a n t a n bu t pe ipher l scul d se ses, tl ti m l p nd m ny tl pa n f h h h at g g es r l ef p bably bera f sod lat f periph r l el F tl p rpos gl w l d t a e g n rally em pl ed l t f som p po es tl mo p net t g d t (7800–14 000 A) obta n ble f m desc t so es e p f ble to th gl w l t t m l t ul t dr pe n th t ues S B sy t THER t THER PY [A C G] B l l g phy O Cl se H d l Ph s s l l 1944 A H ll d (ed) R d n B l g l l 19 4

Infrared spectroscopy

Th tudy f tl e p opert es of mat r al y tems by m ans of the r int ract on with i frared radiati n d p r ed nto a pectrum (se INFRARED RADIA TION) Th infra ed region is valuable for tudy of the str ture of matt r beca e the natural v bra ti nal fr quencies of atom in m lecules an l crys- tal fall in the nfrared ra ge Some eous m le- ules al o l rotati nal fr quencies in the far inf ar d range a d certain fr quencie c rre pond ng t energy le els f electr ns in olids and large molecules c rre-po d t th e of tl e n ar i fr red F r a d t l d di cu i n f molecular brati n a d otation se MOLECULAR STRUCTURE AND SPECTRA

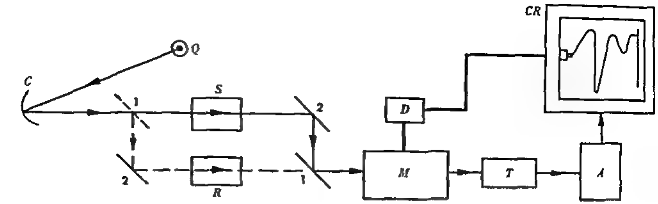
Th i frared ab orption spectrum of a molecule is h ghly har cteristic and often ha been re f r ed t as a molecular fing r print Tl e pectrum a thus b u ed f r m lec l r id ntific ti n Be- au e th ab rpti n of radiat on at art us in fr r d fr q en es quantitati ely related to the umbe of ab rb ng molecules n y tem q anti tati e naly is i al o po s bl

Th usefulness of an nfra ed ab orption spec trum fo identifi ati n and chem al analys s was r c gniz d a l ng go a 1890 I the ea ly 1900 th Am r an phy c t W W Coblentz determin d the infrared spectra f hu d ed f ub tan e and clearly demon trated th potent al alue of uch spectra Unfortunately tl e i t umentati n of that d y was cumber m and nece ar ly homemade th t few phy c ts and chem ts we e attra ted by Coblentz s w k Only afte the developm nt f c mmer ial el tron c de ices for ampl ficat n and e ding of nt n u ly nned pectrum was ext n e e m de f the techn qu Apart f om refi me t s st m nt tion th inf ared pe tra f mol ul s e obta n d tod y n ba lly the ame wa tl t u ed by Coble tz.

Instrumentation and techniques

Th al a an m nt f r measu em nt of an infrar d tec trum i hown hem t c ll in F 1 A ou Q send be m f c ntinu us infrar d radi t on t a sph ri al c nde g m rr r C which passes th amth gh S th mple t be tud ed S me f th inf red frequen e in th beam ab- orbed tro gl some w akly The educed b m pa es n and c m s t a f u at th entra ce lit of th r on l m t r M Th latte is an i f ared p ctr m ter wh h d per e the radi ti n int a sp ctrum One f q e cy t t me appears at the ex t slit f M f m wh ch th ad at of that f qu ncy i p ed b a t ble pt al tem to th detect T The det r (a th rm pl o ther des) c n ert the r d t energy into an elect i al signal wh ch i amplified ele tron lly t A nd rec d d by a chart r d r CR

An f a ed p trum s a cord of ten ty of f a d r d at on as a functi n f frequen y o wa le gth To p od ce u h a reco d th ch rt r ord dri ynchr n ri w th th dis-



F g 1 D ag am of a record g infrared spectromete

persing system of the monochromator M by some common driving mechanism D In this way a given position on the chart corresponds directly to a given frequency setting of M at which setting radiation of that frequency is emerging from M

For many basic reasons—atmospheric ab orp tion variation of source intensity with frequency changing dispersion in the spectrometer and the like—the electrical output of the detector would not be con tant even if the sample S were com pletely transparent To correct for these variations it is necessary to determine two spectra one with the sample S in the beam and one with S removed from the beam The absorption of S as a function of frequency can then be computed from these two spectra The indi idual spectra on which the com putation is based are called single beam spectra

The computation is laborious time consuming and potentially unreliable because of changes in the entire system between the two determinations of pectra The e difficulties are avoided if a second optical path shown in dotted lines in Fig 1 is introduced The second optical path called the reference beam is made as nearly like the first as possible except for the absence of the sample In fact the reference beam may contain an ab orption cell R which differs from S only in the ab ence of the sample itself For instance if the sample S were in solution R would contain the same amount of sol ent as S

The operation of the double beam spectrometer often called a spectrophotometer consi ts of a rapid switching of the beam (say 10 times per econd) back and forth between S and R by alter nately placing plane mirrors 1 and 1 in the optical ystem The identical mirrors 2 and 2 are perma nently placed The pectrum is scanned continu ously as for ingle beam operation but the beams through S and R are compared 10 times per econd and the chart records the energy passing through S relative to that th ough R In this way the ariations mentioned ca cel out

Typical spectra Typical infrared pectra plotted automatically as per ce t t an mi ion of the ample on a linear frequency scale (wave number in cm) are hown in Fig 2 Samples of ga liquids and olids can be read ly measured Techniques for high and low temperature of ample and for small samples (down to about 1 mg or le s in special cases) are in common u e

Per cent transmission T the quantity u ually plotted by commercial instruments is defined as

$$T = 100\, I\ /I_0$$

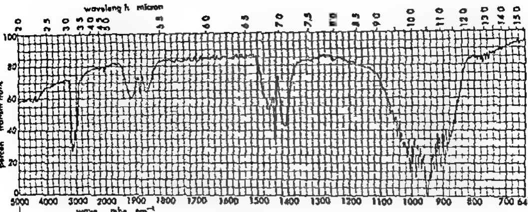
Here I_0 is the intensity of infrared radiation of frequency ν entering the sample and I is the in tensity of the same radiation after passing through the sample The per cent transmission T at fre quency ν is different in principle at different values of A quantity of fundamental importance the absorbance A_ν is

$$A = \log\,(I\ \ /I\ ) = -\log\,(T\ /100)$$

The absorbance A is proportional to the number of absorbing molecules and by evaluating the proportionality constant at frequency for a gi en kind of molecule in a particular system the number of such molecules in other systems of the ame kind may be measured quantitati ely

Applications An infrared spectrum consi ts of a plot of T or A as a function of (or of wa e length λ) The basic information provided by the spectrum is a set of values at which the ul tance is absorbing strongly that is at which T is a mini mum (Fig 2) or A is a maximum The e fre quencies of maximum absorption usually corre spond to the actual ibrational frequencies of the absorbing molecules or to some arithmetical combi nation of such vibrati nal frequencies If the mole cules are in the vapor pha e absorption maxima

F g 2 Typ cal nf a d t a m sio spectra co ded a t mat c lly Not comp e ed scale o left port on of absc (a) Sp ct m f thyle ga T sm s o m ma a g 850–1050 cm r ult f om mod l t on of thyle b at o al f q cy at 950 cm by molec l tat o al f eq e s (b) Sp ctrum of l q u d chlo f m (c) Sp ct m of powde d cryst ll calc m ca b ate Powder w u p d d i m e l o l t obt pectr m T m n m im m at 1430 cm ch act t c of ca bo ate io that at 2900 cm of CH g o p l the o l (d) Spe t m f a amo ph s h gh polym (p ly ty e e) D ta l he e sh ws why f ed pect a a som t m oll d m lecul f g p t



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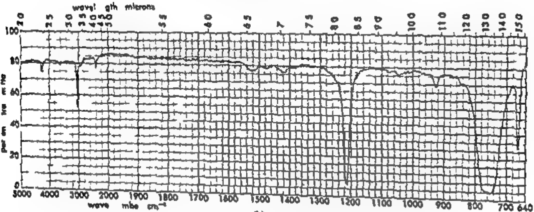
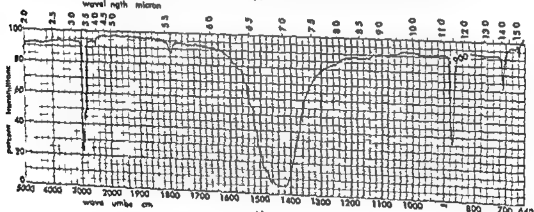


(b)



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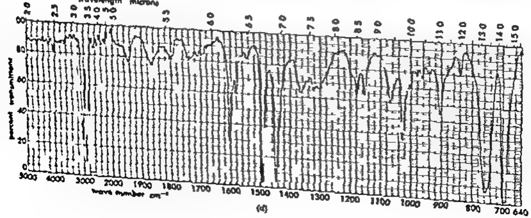
wavelength microns
percent transmittance
wave number cm^{-1}

(d)

may also be observed at frequencies which are combinations of frequencies of molecular rotation and vibration The qualitative u efulne s of an infrared pectrum lies in the fact that the et of ol erved vibrational frequencies characterizes the ab orbing molecule

Qualitative chemical analysis Infrared spectra can be used for the following purpo e

1 To identify pure chemical compounds by comparison of the pectrum of an unknown with previously recorded spectra of pure compounds Catalog of spectra are available and in addition there are practical methods for toring the information in the spectra on punched cards which can then be u ed for fast comparison of unknown and known spectra

2 To identify the con tituents of imple mixtures when the spectra of the possible con tituents are known

3 To show the pre ence of a group of atoms a so called functional group in a molecule of unknown or doubtful tructure It has been known since the 1890 that certain groups of atom —for example a methyl group (CH) a carbonyl group (CO) a nitrate ion (NO_3)—have characteri tic absorption frequencies that are relatively independent of the rest of the molecule or crystal in which the group occur Literally hundreds of such group frequencies are known

Quantitative chemical analysis There is a quantitative relation hip between ab orbance and the number of absorbing molecule thus the quantitative analysis of mixtures by infrared means is fea ible It is also po si le to determine how much of a functional group is pre ent in a mixture or in an impure ub tance though limitations are et on this procedure by variations in functional group ab orbance The infrared method is not particularly sensitive the ultimate limit in detect on and measurement of minor con tituents being in the range 0 1–1 0% except in unusually favorable cases Precision of mea urement is often as good as 1% of the quantity being mea ured but may be considerably wor e Infrared methods are especially useful in determination of isomeric substances and in measurement of constituents of a chemical equilibrium

Determination of molecular structure Structures of molecules can be determined to varying degrees of refinement from infrared spectra If only a few independent parameters (interatomic di tances and bond angles) are required to specify the structure as is the ca e with a mall symmetrical m lecule these can be evaluated from the moments of inertia of the molecule which can in turn be measured from rotational frequencies usually ob erved as fine structure in a vibrational ab orption The structural parameters of carbon dioxide methane ethylene (ee FIG 2a) and ethane for example have been evaluated with high precision from their infrared spectra

If the number of parameters is too large to be determined in this way it may nevertheless be possible to draw conclusions about the molecules hape without measuring its size The number of vibrational frequencies which appear in the infrared spectrum is related to the molecular symmetry and it is often po sible to infer the symmetry from the observed spectrum Such inferences are more reliable if they are ba ed on combined data from both infrared and Raman spectra *See* RAMAN EFFECT

It is still po sible to ay something about the structure of large molecules of little or no symmetry from their pectra if one i content with a tatement about the pre ence or ab ence of various functional group The organic chemi t often find such statements very valuable The nature of fun tional groups in the molecules of high polymers or of natural products such as the steroids can be determined from their infrared pectra and this permits information about their tructure to be obtained

Study of the solid state The infrared spectra of solids give information about modes of vibration of crystal lattices about hydrogen bond vibrations in crystals held together by such bonds and about electronic energy levels in semiconductor and superconductors Hence infrared pectrometers are often u ed by solid state physici ts and increa ed u e of infrared method in this field can be expected especially as techniques for the pectral region 10–200 cm become more widely available *See* SPECTROSCOPY [R C L]

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Inhibitor (chemical)

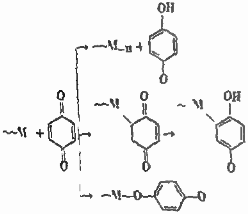
A substance which is capable of stopping or retarding a chemical reaction To be technically u eful such compounds must be effective in low con entrations u ually under 1% The type of reaction which i most easily inhibited is the free radical chain reaction The tudy of inhibitor action is often used as a diagnostic te t for free radical chain characte of a reaction Vinyl polymerization and autoxidati n are two imp rtant examples of the cla s Another reaction type for which inhibitors ha e been found is corro ion particularly in aqueous sy tem The econ mic importance of orro i n inhibiti n can carcely be o ere timated An under tanding of inhibitor action depends on an under tanding f the proce e which are to be interrupted

Inhibition of vinyl polymerization Thi type of inhibitor action must be considered in terms of the accepted mechanism for the polymerization proc e s which may be summarized as

$$P \rightarrow R\cdot \quad \text{initiation}$$
$$R\cdot + M \rightarrow \sim M\cdot \quad \text{initiation}$$
$$\sim M\cdot + M \rightarrow \sim M\cdot \quad \text{propagation}$$
$$2\sim M\cdot \rightarrow \text{termination by dimerization or disproportionation}$$

where P is a catalyst, often a peroxide, R· is a free radical derived from the catalyst, M is a monomer, and ~M· a growing polymer chain. The polymerization will be stopped, or inhibited, if some added substance (an inhibitor) reacts more readily than does the monomer with R· to yield a product which will not sustain the polymerization. Every reaction chain is stopped until the inhibitor is consumed. If the added substance (retarder) in some way is less reactive than the monomer, it competes more successfully for the initiating radical, so that the result is retardation rather than total inhibition. The difference between inhibition and retardation is one of degree rather than of kind.

Phenolic compounds and quinones. These either react with an initiating radical or with a growing polymer chain, either by hydrogen atom abstraction or by radical addition to an unsaturated linkage.



The phenoxy radical products are stabilized by resonance and are not sufficiently reactive to add to the vinyl linkage of another monomer molecule. The ultimate fate of the radical is further hydrogen abstraction by reaction with second polymer radical or by disproportionation with another phenoxy radical to yield quinone and a hydroquinone, both of which may continue to act as inhibitors. All these reaction possibilities have been demonstrated experimentally. Although the efficiencies of phenols and quinones for the interruption of polymerization vary substantially with the monomer, these molecules they may be classed as inhibitors. A mathematical reaction mechanism ...

Nitro compounds. A type typified by trinitrobenzene, trinitro-... function as retarders rather than as inhibitors in many polymerizations. It is necessary, however, to consider the specific reactants involved. These ... in inhibiting the polymerization of vinyl acetate ... that of styrene and have no effect on that of methyl methacrylate. No clear-cut mechanism has been established for the interaction of nitro compounds with free radicals.

Monomers. Both monomers and the radicals derived from them differ greatly among themselves in reactivity. Thus, although certain monomers may readily copolymerize with one another, others may actually function as inhibitors. Styrene and vinyl acetate, for example, each polymerize well when alone. Styrene, however, inhibits the polymerization of vinyl acetate. This occurs because the vinyl acetate radical and the styrene monomer are highly reactive, whereas the styrene radical and the vinyl acetate monomer are not. A small amount of styrene added to vinyl acetate will rapidly react with any vinyl acetate radicals formed when polymerization is initiated. The resulting styrene-like radicals will react only very slowly with the vinyl acetate monomer. In the overall process the chain-carrying radical is converted to one which is too unreactive to carry on the chain.

Autoinhibition. This action, sometimes called allylic termination, is exhibited by monomers which contain the highly reactive allylic C—H linkage. Free radicals are capable of hydrogen atom abstraction from copresent molecules as well as of addition to an unsaturated linkage. The ease with which this abstraction reaction is carried out by a given radical is a function of the reactivity of the C—H linkage which is attacked. The reactivity of radicals containing these C—H linkages increases in the order aryl < primary alkyl < secondary alkyl < tertiary alkyl < allyl < benzyl. Because of this high reactivity, a monomer containing an allylic C—H, allyl acetate for example, functions as its own retarder.

$$\sim M\cdot + CH_2{=}CHCH_2OAc$$
$$\swarrow \qquad \searrow$$
$$\sim MCH_2\dot{C}HCH_2OAc \qquad \sim MH + CH_2{=}CH\dot{C}HOAc$$

The resonance-stabilized allylic radical will react with the monomer only very slowly. The products are not further reactive to dimerization. Not only is polymerization slowed in this way, but the molecular weight of the polymer formed is low.

Miscellaneous inhibitors. Oxygen, iodine, and nitric oxide react rapidly with free radicals to yield stable products. Inclusion of these materials in polymerizing systems leads to effective inhibition. It is of particular interest that oxygen will copolymerize under carefully controlled conditions with certain monomers, styrene for example, to yield high molecular weight polymeric peroxides. The repeating unit is

$$[\text{—CH}(C_6H_5)CH_2OO\text{—}]$$

Iodine and nitric oxide have been used to selectively detect and in some cases to identify alkyl free radicals. Iodine in no chain reaction as well as ... has no reactions. This method has proved to be of great value in defining primary processes in photochemical decomposition of aldehydes and ketones.

Inhibition of corrosion Metallic corrosion in conducting media is electrochemical in nature Local electrolytic cells are set up because of the presence of impurities crystal lattice imperfections or strains within the metal surface The result is dissolution of the metal from the anodic regions Corrosion inhibitors now in use may operate at the anodes or the cathodes or provide physical protection over the entire surface

Anodic inhibitors These are mild oxidants which reduce the open circuit potential difference between local anodes and cathodes and increase the polarization of the former Sodium chromate and sodium nitrite are most commonly used The former is used in air conditioners refrigeration systems automobile radiators power plant condensers and similar equipment Sodium nitrite finds special use in the protection of petroleum pipelines It is effective even on rusty mild steel An extension of the nitrite type is the use of nitrite salts of secondary amines as vapor phase inhibitors The inclusion of a salt such as dicyclohexyl ammonium nitrite with a packaged steel object provides effective protection against corrosion

Cathodic inhibitors Compounds such as calcium bicarbonate and sodium phosphate in an aqueous medium deposit films on metal surfaces which provide physical protection against corrosive attack

Organic inhibitors These are usually long chain aliphatic acids and the soaps which are derived from them Adsorption of these compounds on metal surfaces gives a hydrophobic film which protects the metal from corrosion by many agents As little as 0 1% of palmitic acid for example is sufficient to protect mild steel from attack by nitric acid *See* ANTIOXIDANT CATALYSIS CORROSION FREE RADICAL POLYMERIZATION [F H S]

Ink

A substance used for writing marking drawing and printing which is transferred by several methods to a wide variety of surfaces such as metal fabrics wood glass or plastics Inks consist of a vehicle or carrying agent and a colorant that is evenly dispersed throughout the vehicle In the United States inks are produced to the value of $300 000 000 annually

Writing inks *Writing inks are known to have* been used as early as 2000 B C For many years they were made from tannins and galls obtained from bark or nuts but with the spread of literacy their varieties increased Even inks used for typewriter ribbons may be considered as a special form for writing Modern writing inks are composed chiefly of aqueous solutions supplemented with gums or glues and dye colorants to which small quantities of pigments may be added The writing ink industry is distinct from other classes of ink manufacture

In the modern office duplicating machines are in common use Technically they are not writing machines yet they do use ink specially suited for each particular class of machine Proper inks are usually supplied by the maker or distributor of the machines

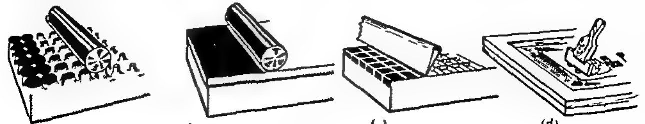
Marking inks These are the successors of man s efforts to make his mark with any medium available In shipping departments of industry and elsewhere inks are used with rubber stamps stencils or special brushes to mark a great variety of surfaces of wood metal and fabric There are many varieties from liquid to solid which may be composed of a water alcohol oil or wax vehicle with either dye or pigment colorants

Printing inks Printing inks are used on printing machines from the small job press to large high speed multicolor presses which produce printed matter in great volume and variety with four printing systems to transfer thousands of types of ink onto hundreds of different types of surfaces

For instance a book may be bound in cloth cover using a bookbinder s ink printed on a platen press it may have illustrations printed with process inks on a cylinder press and bound with the text pages or on a slip cover The text or reading matter may be a book class of paper and run on a rotary press with a book ink Such combinations are not unusual Inks may be labeled with different names designating either the class of ink or the end use

There are four distinct printing systems for transferring ink to paper or other surfaces (1) letterpress or relief printing in which the type or illustrations are above the surface to receive the ink from distributing rollers (2) lithography in which ink is transferred from a level or plane surface (3) intaglio in which ink is transferred from a depressed surface (includes rotogravure gravure copperplate printing steel die embossing and metal etchings) and (4) silk screen in which a roller squeezes ink through a piece of silk stretched on a frame to paper or card underneath the frame (Fig 1) *See* PRINTING PLATE

Each system requires different inks for different presses and papers but the printing ink industry is generally a custom prescription one This re



(a) (b) ( ) (d)

… tem for k t sfe (a) Rel f (b) Plane (c) Dep d (d) S lk e

qu res a f rmula made f r th parti ular tra sfer methods v hicles adapted f r press operatio nd pigm t color nt co d ng to th ir end u e The formula s refully reco d d by we ght of the i gred ent a d i g number R peat rder for add t on l or lat r ru mu t be exa t t the mall est tolera espe ally for u n label and pack ag p int ng

Printing ink vehicles The p inting ink form la f r the eh cle w ll be pr pared to suit th follow i g e nd t (1) the p i t ng sy t m u ed (2) th cla nd speed of the press (3) th dry ng process r q i ed (x dat o penetrat on evapora t on o g lat on o p p t on) (4) the class nd t xtu e of t u f ce to be printed (5) the at f the p gment r q i ed d (6) any pe i l f nct o f the p nted m tte which may p- pl i both eh cle and p gment.

The m i ehi les sed are mi e al o l h at bod ed l n eed va hes with e n tent es fr m N 5/0 (ery thi l to No 9 (v ry iscou lik st cky m l ses) h naw d tton eed or p rilla l al oh l glyc ls and hyd oc rb n s l ents These a d othe m y be u ed s ngly or m de into rni hes by the add t on f dri esins, gums r th r ld ti es to pro ide good w k ng quali t es on the pr s Addit es r u ed t mp o fin t h, h d e fl xib l ty f th k f lm V rn h i gred ent may b prep ed by d s l ng ook g mix g or di per i u r by runn ng them to- g th thr ugh a nk mill Sp c alt e e pur h sed by the k m ke f m t de upplı r

Colorants Th nk film i very thin (bo t 0 0001 i) T nsp r cy s as eces ary f r some p po es pac t f r th rs The same film w ll ch nge i lo pp a n when sed n d f fe nt u f ces su h s book and ated pape s bec e f th l ght sc tt ring of u f t xtu e l ght penet t n t th fiber or n t on i the h t nes f th h t

P gme t manuf ctu a mpl ated ch m l nd t y wh h s ppl es mo t p nt g ink color l B th g ni and rganic p gm nts a e sed P gm nts f a i t ol w ll d ff r i n m f th foll w ng w y pa t cl ze wetta b l ty pec fi gr ty pa ty olo trength dry i g t m i d ff e t h le a d es t n e t t t k f m l ght h t alkal a id gr ses fat a d wa

B k p gm nt bon bla k nd t g t d n ty blue ol r t m b ed Am g th wh t p gment t ta i m d de s ed f hu k a d bl c fi e al m na hy d t n des nd k l n d f e ten l ra

Th asm f m ly f p gm t m y be prod ced t es l h des Chrom y ll w run f m p m t e n th g d t g lden n th red ide Ch f f m l es ed —l th l i l d es tu g t es m l bd te y ll w —ch m s, Ha a, ben f hl n ll u M l r refl x pl th locya pe ek g een—phth locya r mi r e f ll w d l) d p plee—phthalocy n ne m t r l red d llu

All pigment must be thoroughly d per d and r finely m ll d on roller mill colloid mill or b ll mills to pre ent reagglomerat on See DYE PIGMENT

Special inks New inks are u ed f r printing on n wspr nt pape s New black for met op litan dailies i a thin l qu d ink f eque tly deli e ed by tank truck and pumped nto torage tank f om whi h it i pumped to the p e s For the we kly newspaper with smaller pres es a l ghtly th cker on i tency s u ed th s m y be del ered in kits o drums Blacks are made with mineral il and carbon black a d dry by p netrat on

The e of new pape col h s i c ea d very ap dly a t end wh ch will c ntinue Inks u d re n med ru of pres (ROP) olo Comic colors de ign te inks u ed t print the comi upplements of new paper a well as comic booklets usually n spec al pres es Their properties are imilar to tho e f news black

Bookbi ders ink used f r p int ng cloth r pl sti book cov r re heavy i cou inks made fr m li seed o synthet c varni hes Th y dry by oxidation

Co er nks are the opaque i ks u ed for pri ting o colo d p pers

Th c lors u ed fo three four olor illust a tio s known as pr cess i ks may be used on all print ng y tems. Col rs select d are r d yellow and blue which when p ope ly run pp a to re produ e th tire chromatic spectr m

Metallic nks ar c mp ed f a speci l a ni h nto which a e m ed fi ly flaked l m um pow d r to represe t s l e a d c mb nat ons f b s a d pp r fl ke to e mbl g ld

He t set inks nam d for a dry ng method are c mpo ed f pec al f act s of mineral l with synthet c res s wh ch r main stable at r m t m pe atu e but evap rate r pidly wh n run over a he t ng nit tt l ed to the press at temperatu es of about 1500 F They are s ted for large editi ns f m gaz s a d catal g

M istu e et ink d p nd on an the drying p oc e They h ve eh les of gly ols and alcohol solu resin which pr ip t te the p gment con t t with moistur The r hief u e i on wrapp ngs a d packages whe f ed m f om dry g od r i mp rtant

Fl xog aph c nk (f rm ly named a li e inks) ed n pe l p es e w th rubber printing plates They a e b ng ed n r s ngly e p c lly f p ck g w apping u h a fol t a pa e t pl sti film r p p r b g ma h nes Th y are omp ed of l oh l h ll r othe olatile ol ents a d now e nts n p gment e l a t They are liqu d i n tency and dry by ev p tion

M gn ti nk a e a new typ of k now r e i g atte t n f u e on ort ng w th el ctronic eq pme t

Lithographic inks l th graphy was in nted by Al i Se l ld in the e ghteenth ce tury a d ha h wn great p g e s n e 1900 be au e of the in t oduct n f the t ry ff t p e and the appl ati n of phot gr phy n th m k

system has great versatility for use on financial printing such as stock certificates, bonds, and checks. It is used for advertising matter, displays, billboards, fine art reproduction, greeting cards, packages, and metal decorating. The inks used are of heavy viscosity, made chiefly from linseed oil varnishes or combinations of mineral or other oils with synthetic resins and pigments that are resistant to water. They dry mostly by oxidation. In the tin decorating industry, for containers and signs, the drying process is speeded up by the application of heat, and the ink film requires greater flexibility.

Offset inks are lithographic inks used on a press which transfers the ink first to a rubber blanket and then to the printing surface.

Dry offset is a relief variant of the offset system. The plate used is given an etch which produces a slightly raised surface. The ink is run on an offset press without water. This process is used frequently on check backgrounds or sales slips for protective purposes against the use of ink eradicators or erasers.

Intaglio inks Intaglio is the printing system in which the image is depressed below the surface. There are four classes: rotogravure, gravure, die stamping, and copperplate. Rotogravure is used extensively for newspaper supplements, catalogs, and packaging.

Rotogravure inks are liquids that are filled into tiny wells (as many as 40,000 per square inch) etched on a plate or cylinder. A scraper blade removes the surplus ink from the surface, and the ink is transferred to the paper, drying by evaporation. The vehicles are chiefly hydrocarbon solvents and alcohol.

Copperplate inks and die stamping inks used for personal and business stationery are buttery pastes in consistency. Both require special varnish properties for their use. Because the plates are cut much deeper, the film of ink transferred is much thicker.

Silk screen system The silk screen process is well adapted for display card advertising, but has

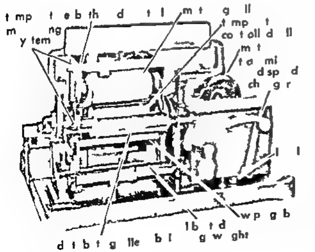


Fig. 2. An Inkometer. (Thwing-Albert Instrument Co.)

many other uses. When fluorescent pigments are used, brilliant colors are obtained. The process is slow, but mechanization is increasing for longer runs. A piece of silk is stretched onto a frame. The nonprinting areas are blocked out, and the ink is squeezed through the silk with a roller to the paper or card underneath. The inks are of buttery consistency, with a film of good thickness which dries by oxidation.

Manufacture Printing ink manufacturers maintain their own laboratories staffed by chemists and color matchers for formula development, production control, and testing. One of the instruments for testing the tackiness of ink for press qualities is the Inkometer (Fig. 2).

A Printing Ink Research Bureau is operated at Lehigh University, Bethlehem, Pa., and is supported by the National Association of Printing Ink Makers, New York. See PRINTING. [C.R.C.]

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Inland waterways transportation

Nearly 9% of the national intercity freight tonnage moves over the 29,000 miles of navigable inland waterways in the United States. This system of natural and improved rivers and man-made canals is the most extensive, highly developed, and efficient in the world. The equipment used in the towing trade is modern, specialized, highly refined, and includes powerful towboats, barges of all sorts, and the latest in navigational aids. The largest tonnages travel over the Midwestern network of rivers, but substantial volumes of bulk cargo also move in the East and Far West.

Generally speaking, inland waterways transportation is lower in cost than any other mode of transportation except pipeline.

Many American methods of large volume towing are now being practiced in other countries where water transport, always of key importance, had never handled such great quantities of cargo with such powerful and labor-saving marine equipment.

Commodities moved Coal, petroleum products, sand and gravel, and grain are the principal commodities barged over the American inland waterways system, but many other products are also moved on the rivers in large quantities. Most important among the newer cargoes are a vast variety of chemicals moving in specially designed tank barges. This increase in chemical tonnage has taken up much of the slack created by the switch of many petroleum products to pipeline for transportation.

Smaller lots of cargo less than a barge load comprise only a small portion of the total tonnage moved, although several towing concerns in the

Fg 1 F d l B g t U t d St t the wo ld m t p werf l t wb t The bo t w s bu lt by th St t Sh pb ld g & Ste l C d p w d by f d f g d f p g t t l f 8500 hp

Ea t part ula ly dev te a great porti n of th b n t packaged bulk hipme t

The t da d r er b rge l ad n s in the ne h borhood f 1200 t n n a ba g 195 ft l ng by 35 ft wid w th l aded d aft f 9 ft The ba ges e d gned to fit th ee l ng by th ee w de t a tand d 600-ft by 110-ft n r lock

O th M dwe t rn sy tem of rs many s h b ges a e la hed t g th r ant h g t ws p h d l y h lly d el t wboats Th mo t pow rf l tow bo t fl at n 19 9 w th 8500-hp F deral B rge Li es In M Y *Un t d Stat* (F g 1) wl h ca h e 40 m r l ad d b rge on the pen t f tl Lo M pp b tween St L u d N w O l n at pe d of o er 7 mph Su h a t w m ght ve m e th 7 c es be th yd f mil l g c rs m h l ight a 1000 ail ad about f ur a erag oc n fre ghter a d y t m s through a arrow d metimes d g 9-ft de p han l 24 h r a day in an k d f th (F g 2)

In th Ea t and Fa W t mall r load ar e q ed l ecau l d ff re t pe at ng nd t n Most f th se a pec ally n p n wate mos f p ll t w ng n wl h co t n l tugboat pulls one barge or a string of ba ge on trong l aw S me pu h towing is u ed in the Ea t (on the N w Y rk St t Barge Canal and tl e Atl ntic Intr coa tal Waterway for example) but u ually it moves o ly one b rg at a time be au e of se e lock and chann l l mitations Haw er t w ng is tr d t onal th o gh t tl e w ld and only in the 19 0 d d oth r nation (n tably France G m y d Ven uel) begin using the more ef fic ent p sh tow ng method on a lim ted but highl u f l basis

Great Lakes By C a t Gua d defin t n C e t Lakes shipp ng is n t a f rm of inland waterways t a po t t n. Howe er the t nn ge m ved o er th Lakes yet m s alm t equ l to the total mo ed n the i land wate way Mo t Gre t Lakes t nnage n ts of o e m ved in large (up t 700-ft) f ei hte s F r addit onal informati n *see* SHIP MERCHANT

Navigation projects The inland waterways of th Un ted State re ma ntained at spe ified d pth by th U S Army Corps of Eng neers The Co ps al o exe c es s p rvi ry a tho ty o er new river onst u ti n p ojects I f cal year 1959 Cong es app priated o e $800 000 000 fo ri e nd ha bo s imp ovem t a d for recurring water w ys mai te an Thus um was allotted not only fo mme ci l na g tion but also for flood con trol irr gati n hyd oelect c power pr jects on erv t on d ec e t n l f at ng

The majo w terway pr ject of th Federal go ernme t in ol e the c al zat on of exi ting r e The ugh s e of dams th proce cr ates sl ckwater pool along a er wh h c th be eas ly na ated ma ntai d to pe depths a d nt oll d t el minate flood hazard Th b ge t projects nd rway in 19 wer as f llow

1 The Ohio Ri r whe e the xist ng 49 d ms w e to b replaced with 19 high dam and th

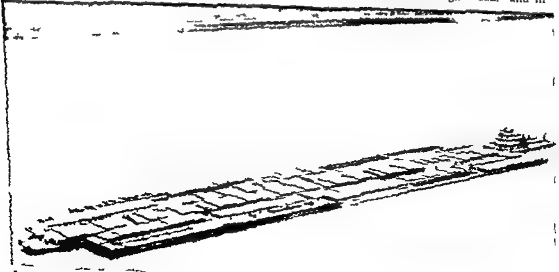


Fig 2 F d l B g L e U t d St t hown St L p h g t w of 42 b g Th hug t w north f Che ill b d p the M ppi R e t w pp mat ly 7½ n a

locks to be increased from 600 ft to 1200 ft in length

2 The Columbia and Snake rivers which when development is completed will be navigable to Lewiston Idaho and studded with huge multipurpose dams

3 The Missouri River which was to be fully canalized and raised from a 5 ft minimum depth to the standard Midwestern 9 ft minimum depth

4 The Illinois Waterway where locks were to be made two way to ease current congestion and accommodate additional traffic generated by the opening of the St Lawrence Seaway

5 The Warrior Tombigbee Waterway in Alabama where lock capacity was to be increased

6 The Trinity River in Texas which was to be canalized to create a 9 ft channel from the Gulf Intracoastal Canal as far inland as the Dallas area

The renascence of the inland waterways as the heavy haulers of industry is a fairly recent phenomenon in American history In the early part of the twentieth century river traffic was almost eliminated by railroad competition However in the 1920s as government canalization programs progressed and new machinery (particularly diesel engines) and new equipment found their place on riverboats the industry revived and has been growing in importance ever since (see Fig 3)

Machinery and equipment Prime mover of the inland waterway boats is the marine diesel engine equipped with a reverse reduction gear This gear enables the diesel to operate at maximum high rpm efficiency while turning the propeller at its far slower but most efficient speed See MARINE ENGINE

The riverboats of the Midwest are basically rectangular in shape some as long as 200 ft and are characterized by heavy pushing knees (vertical pushing braces) forward and propellers encased in Kort nozzles aft The Kort nozzle basically a funnel like cylinder surrounding the propeller can increase the propeller thrust by as much as 40% in certain cases See PROPELLER MARINE

Towing in Eastern and Far Western waters is handled largely by conventional tugboats smaller in length and beam than the riverboats and built with stem type bows molded hulls and rounded sterns

River barges fall into three categories—open hopper covered hopper and tank barge These are designed respectively to handle weather resistant hard goods vulnerable cargo and liquid products

Originally almost all barges were designed with a rake (overhang) fore and aft and this is still the most efficient design when barges are towed singly However as large fleeted movements of barges became common on the rivers many new barges were constructed as integrated or semi integrated vessels These are designed for high towing efficiency in tows of many barges An integrated tow will have one lead raked barge with a square stern a number of square bow and square stern barges and finally a trailing barge with a raked stern This type of tow presents a single underwater surface like a single complete vessel and towing speeds can be proportionately higher However barges with two square ends are extremely unwieldy if it becomes necessary for them to be towed individually

A semi integrated tow is composed of single raked barges arranged square end to square end This causes comparatively few breaks in underwater continuity of the hulls and yet enables the barges to be towed singly when necessary

Types of carriers Cargoes are moved along the American waterways by three types of water car

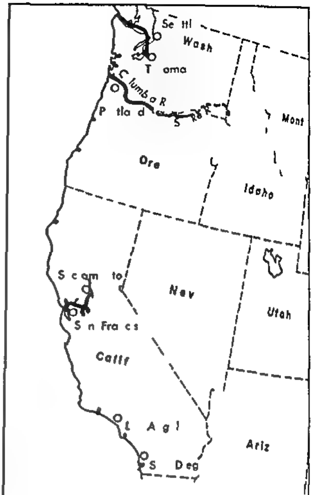
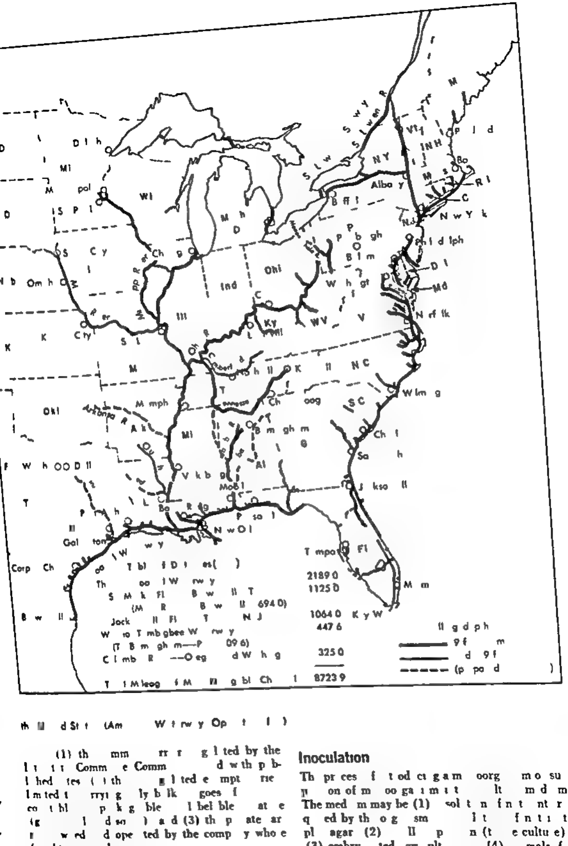


Table of Distances
Principal Inland Waterways

Mississippi R —Minneapolis to Gulf	1839.1
(to New Orleans —Cairo Ill 1724.0)	
Illinois Waterway	321.1
Illinois Mississippi Canal (Hennepin)	75.0
Ouachita R —to Camden	350.8
Missouri R —to Sioux City	760.0
(to Kansas City 377.0)	
Ohio R —to Pittsburgh	981.0
Monongahela R	129.0
Allegheny R	72.0
Kanawha R	90.6
Big Sandy R	44.7
Kentucky R	258.0
Cumberland R	191.0
Tennessee R	650.0

Fig 3 Commercially navigable inland waterways of



th ll d St t (Am W t rw y Op t l)

(1) th mm rr r g l ted by the I t t Comm e Comm d w th p b- l hed tes (l th g l ted e mpt rie l m ted t rryi g ly b lk goes f co t bl p k g ble l bel ble at e (g l d so) a d (3) th p ate ar r w ed d ope ted by the comp y who e f ght ed

Tonnage Th m t f g m d 1957 391,889 000 t f t t l f 114,561 000 000 t m les. E t m tes f 1958 ar l ghtly h ghe S C t D M R t [n w]

Inoculation

Th pr ces f t od c g a m oorg m o su on of m oo ga i m i t lt m d m The med m may be (1) sol t n f n t nt r q ed by th o g sm l t f n t i t pl agar (2) ll p n (t e cultu e) (3) embry ted ult (4) mals f mpl rat, mou e gu a p g h m ter mo k y b rds, o h m n b g When m l are used th rpo e ally th a t t f th mmu olog i l d f se g t the orga m Th i form

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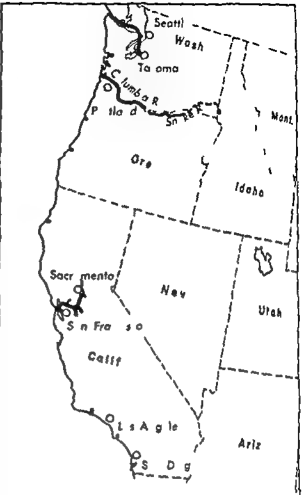

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Fig 3 Commercially navigable inland waterways of

ph ru il on and rel ted c mpound and an array l vacuum l es is frequently th hallm rk of a labo atory f r synth t c mo gan c chem try

Organometallic compounds Metalloorganic c mpound n titute a borde l ne area of tudy ly g bet een i rg nic and orga chem try U til 1950 although a con d r bl number of metallo-rgan c c mpou d wa known th we e all de ed fr m m tal that bel ng t the pr nc pal fam il es n th period table no stable de i ati s of ubg up m tal r t an t n m tals had been p e pared despite m ny ttempt N w a large n mbe f met lloorgan c c mpo nds f th t an iti n nd bgr up el me t w th cy l p nt d e e ($C H$) a d w th aromat c hydroca bons u h as benzene (C_6H) h been s nthe zed B ca th c m pou d fo m nt e ti g d i ati es with carbon m x d CO and unde go numero ther re c t s, and beca the ex ten e of th se c mpo nd poses inte est ng th oret al p obl ms many i ves t gat e c n erned the n elv s w th this fi ld f re ea ch It a be nti ipated that th a ea will bec me f e ate ign fica e in th ino g n c ch m try f th future S e ORGANOMETAL LIC COMPOUND

Solid state chemistry The el ment and c m po nds th t f rm the ubject *matter of* n rg n c h m try exh b t ery wide a g l phy cal p p rt es and un the g m t from b l m th b tan e of l west m lt ng and bo l ng p i t to metal x des a b des a d t d s wh ch a mo the most fra t ry high melt ng ub tanc kn Th t dy f l d tate r a to d c mpounds ha a med t mportan e i ent y a and t th r maj r ar f re r h in n rg n h m try Unl ke g eou c mp unds nd m t r ga mpo nd which f ll w th law of d fin t pr po t s very l ly many l d compound p rt la ly those of th t n it n leme t ex h b i *nstabil ty f* mposit on o as t f e ei tl des g t d m to ch m try When a sol d mpo nd d tes f om imple t ch met r rel t i w ll t in a e ce s t ther po i ly ha ged met l m s n gati ely h ged a n l d el condt n the s l d l eq ntl h w u j l t t pr p rt es that t m d f n h t f l d t t dev ces Sol d hos lect l pr pe t are a f n t n of d nt l ght bel ng to th gr p a d photoelec t de es a n t ted *of* n h ub ta c T n i t th m i r a d ph ph s e ther sol d t t dev es f i d ly a g mpo t the mate ls e l d mp und d f q il p pa ed by sol d phase r c t n h gh tempe at may be t l ed n th heses H gh tempe i r h m try h s greatl p led n ter t n t ly n nect th th p pa t f n n t h m tr m p l t i lso f th p pa t f rel t ries u f l at h gh t mpe t r m rock try d url techn l gy Alth gh m y r t n le f t rd t proceed m l b a g the t m p i fic ently th i t in tself adeq t f r all p rposes and in the very rec nt p t, a n w d men io has been added by the multane ous u e of ery h h pre ure With the equipment now availabl it i pos ble to carry out olid tate r actions at tempe ature f approxim tely 2 00 C (453 F) and 200 000 atm (3×10^4 p i) Under these conditi ns rd ary a bon (graph te) can be c n erted i t d amo d and m e th p su e i ct ally suffic nt to d tort the electron rb tal new vari t es f m tter can be obtained Thu it i po s ble t make a new a i ty of l ca which unlike the u ual nes rea t with hydr fluoric acid t a v ry ma kedly reduced ate Und ubtedl hi h pr s ure–high temp r t r h mi try i de t ned to bec me one of the *mo t mp rtant ar as of* e ea ch in inorganic ch em stry

F r ma y solid tate device it i f the greate t importan e to h ery pure *m terial* a *material* with just th c rrect amount of mpu ty F r t an i rs it *f the greate* t import nce to e are il c n e tai i g the rde of a f w parts pe b llion f impu t es Thi i ommonly ach e ed by a omb nati n f chemical and phy al procedure including zone melt ng Th prep rat on f *ultra* pure i o ganic c mpounds i al ital in the prep ar ti n of lumi scent and phosph e cent mate rials

Geochemical aspects Many f the synth tic pr edures a ed ut at h gh temperatures and pre ure ha c n id able int r t geo hem s try *Perhap th a l e t* organ ch m stry was pra ti ed n onnecti n w th m ne al gy M n al ynthe es or the p p ration of norgan c om pound de tical w th tho found in n ture ar *m rea* gly ce py ng the att nt on of the nor ga ic chem t Not nly is thi of c entific mpor tan in xplain ng the eq en e of ch mi al eac t on nd co d t n e p ns ble for the f rmati n of th *mineral* m nat re but many m l d gems f indu trial mporta c c n n w be ynth s ed s me n th la g indu t al s le d am nd uby pphire qu rtz, corund m Either high tem p ratu e acti s hydroth rmal r a t on ea ed t w t r at h gh temp ratu and pre re a e mpl yed With the ad ent of ltrah gh p s re equipm nt it n w bec mes fe ble to tud h mi l re cti n und r cond tions ppr x mat ng tho e ma y m le b low the earth s u f Such stud can rely b e pe t d t make a ma jor contr buti n t the nd r ta di g of ge h mi al ph n mena. See HIGH PRES URE PHENO IE A

Nuclear technology The de lopm nt f n clear technol gy ha pro ided gre t impetus to ino ga i hemistry Th fforts of th no gan hem i t ha e bee nd pen able to the c ful t l zat n l nu l a e gy The d c very f the t an r n m lem t n of th ut t ndingly import nt ev t n hem l s i nc h pro id d h t of pr bl m It has been n ry to e pl n deta l the chemi try of th ctin de ele me t i ord to d t m ne h th e new ele m e we to be in orpo t d nto th period t bl a d f r the immediate p act cal purpose of

of vaccination and quite often the two terms are used interchangeably Both constitute a means of producing an artificial but active immunity against pecific organisms although the length of time given by such protection may vary widely with dif ferent organisms *See* VACCINATION

Inoculation is the natural process of acquiring protection against disea e in that most persons are expo ed to some organisms at times when no severe symptoms are displayed The protective mecha ni ms of the body especially antibody production are stimulated by such a mild or insignificant ex posure An example of this is the discovery that the majority of adults have antibodies to poliomyelitis present despite the ab ence of a history of the se vere or recognizable disease form

Inoculation may al o refer to the deliberate seeding of organisms into culture media and the introduction of fermenting bacteria yeasts or molds into variou indu trial processes that employ the chemical reactivity of the e organisms *See* IM MUNITY MICROBIOLOGICAL METHOD [E C ST]

Inorganic chemistry

The chemical reactions and properties of all the elements and their compound with the exception of carbon hydrogen compounds Inorganic chemis try is thus defined by subtraction The chemistry of carbon hydrogen compounds forms that province of chemistry designated as organic chemistry All the remaining elements in the periodic table fall in the domain of inorganic chemistry The boundaries with other major disciplines in chemistry are not precisely defined however and it is often difficult to allocate a given topic to the field of inorganic chemistry or to physical chemistry Physical chem istry may be defined as the application of quantita tive and theoretical methods to chemical problems and is a methodology rather than a specific body of knowledge Investigations into theoretical inor ganic chemistry or the study of problems in inor ganic chemistry by quantitative and sophisticated physical methods may be considered to be inor ganic or physical chemistry quite arbitrarily In similar fashion metalloorganic compounds may be con idered as being either in the sphere of inor ganic or organic chemistry To an increasing ex tent the inorganic chemi t concerns himself with problems that once were considered the preroga tive of either physical or organic chemists and to day the inorganic chemist is frequently indistin guishable from the physical chemist

Because inorganic chemi try concerns itself with 100 of the 102 elements in the period c table its scope is very broad Nevertheless some natural divisions exist and it is convenient to treat the sub ject under the headings of synthetic inorganic chemistry theoretical or physical inorganic chemistry and applied inorganic chemi try

SYNTHETIC INORGANIC CHEMISTRY

The reactivity of the elements of the periodic ta ble varie enormou ly and over a much wider range than is encountered in organic chemistry Con e quently the inorganic chemi t must frequentl employ unusual apparatus and techniques The elements range from the rare ga es which are completely unreactive and form no chemical com pounds to the extremely reactive halogens and al kali metals Fluorine is perhaps the mo t reacti e element known it forms compounds with all other elements except the rare gases The study of the chemical behavior of fluorine and its compound has been a major activity in inorganic chemi try in the last decade Fluorine compounds are impor tant in the separation of the i otopes of uranium a refrigerants anesthetics chemical warfare agents and potential rocket fuels and for many other pur poses Because of the great reactivity of fluorine and the closely related halogen fluorides pecial metal and plastic apparatus mu t be used in ex perimentation Both fluorine and the important fluorine compound hydrogen fluoride attack gla and thus the most common material of con truction used by chemists cannot be used

Another element important in synthetic inor ganic chemistry since World War II is boron The hydrides of boron were first discovered ome 50 years ago but it is only within recent years that the chemistry of these compounds has been clari fied The evolution of synthetic procedures in b ron chemistry is an instructive example of the method of the inorganic chemist The hydrides of boron were first obtained by reaction of a metal boride with a solution of an aqueous acid The procedure was very difficult and tedious and it required week or months of labor to obtain a few cubic centime ters of the gaseous product which turned out to be the simplest boron hydride B H Many years later it was discovered that yields could be increa ed substantially by passing boron trichloride and hy drogen through an electric discharge but here al o the yields were very low Under the impetus of wartime urgency chemical synthe es for the bo ron hydride were developed Using the read ly available compound alkali metal hydrides and bo ron trifluoride a starting materials boron hy drides were obtained in very go d yield In addi tion to diborane B H a con iderable number of other boron hydrides are now known B_4H B_5H B_5H B H_{10} B H_{13} and B H and many deri a tives of these have al been synthe ized Com pounds that contain the b rohydride group BH_4 have been prepared and the metal bor hydride are now very important comp und Aluminum boro hydride Al(BH) i of intere t a a po ible high energy fuel and d i m bor hydride NaBH i a widely u d redi ing agent Many of the e b ron compo in ls rea t vi lently with air and water It is nece ary theref e t i e pecial equipment in tudying them an l ll gla acuum sy tem ha e l e n le i ed f r ying out experi m nts with the ery rea ti ul tan e Vacu im line technique are wid ly i ed in inorgani l m i try for the manipi lati n of latile highly reacti e comp iund si ch th hy lri le f jh

phoru lc n, a d related mpounds and an array of ac m lines is frequently the hallmark of a l borat ry f r ynthetı morg e h mı try

Organometallic compounds Metalloo g nı mpo nd n t tut a borde l n area of tudy ly mpo nd ı n rgan a d organic chem try Until 1950 alth ugh a co de able number f met llo-organ c mpounds w kn wn the were all de ed f om metal th t bel g to the princ pal fam l es the p riod c table no t ble d vati es f bg oup metal r tr iti n m tals had bee p e ed desp t m ny attempts N w a large numb r f metalloo gan c comp nd of the tr ti n and bgr p el me t w th cycl pent die e (C H) and th a omatı l ydrocarbon uch a benzene (C_6H) have bee synthe i ed Beca e th e c m pound form nterest g d r vati es w th carbo m ide CO and und rg n mer us othe r ac t and b cau e the exi t ce of th e ompounds po es i terest ng theoreti al p oblem many nves t gat rs ha e co c d them el s with this field f resear h. It n be nt ip t d that thi a ea will ber m f es n gr ater s gn ficance ın the ın r g ic chem t y of th future S e ORGANOMETALLIC COMPOUND

Solid state chemistry The element and m pound that form the ul je t m tt r of in gan c hem t y exh l t a ry wide r g f phy cal propert es and run the gam t f m hel um the sub-tan f l we t m lt g and bo l g int to m tal ox des, arbides and t des which ar am ng the m t r fra tory high m lt ng ub ta ces k w Th tudy of s lid t te r ti s and c mp u d ha med p at mport n ec nı ye r and ther m i area f e ch n rg n h m try U l ke g u c mp nds nd mo t r ga omp u d whi h f llow the law of defin te pr port ery l ely m ny sol d compound p tt l ly th f the tr t n eleme t e h b t r b l ty f ompo tion o a it i fre-q ntl d gn ted n t i hiometry When sol d mpo nd der tes f m s mple i h met r l s n tt tll nt n a exce of eith po t lv h ged m tal cati r n gat ely h rged U d r h nditı s the ol d f eq tly h w n al lectr c propert es that a m d l t f sol d t t devi S l d hos l i l pr pert es a a fun ti of n l t l ght bel g t th g and phot lec i dev es e tri ted f n ub t n c T t th rm s d ch ph a ther w l l t d f t adly i e g mp t n thes mat al a sol d c mp und l f q ntly pr pa ed b t d pha eac h h t mpe t es m y be t l ed the thes ll gh t mpe tu e h m try h greatly pan led ec nt t nly nn t n th h p p t l n t r h m t ic n w l l t l f r th p r r ti f f t ries l l a h gh tempe t es n ock try d l tech l g Alth gh m y act a t l ed t p ssed m l h r g th tem r at r tl thi n t t tself d qu t

for all purp es and ın the very re ent past a new dimen ion ha been added by the s multane ous n e of ery high pre ur With the q ıpment now available it is pos ible to carry out ol d tate reacti ns at t mp ature of appr ximat ly 2500 C (4532 F) a d 200 000 tm (3×10 p i) Under the e conditi ns ord nary carb n (graphite) an be con erted into d amond an l s nce the pre sure s a tually suffi ient to di to t the electron orbital new riet e of m tter can be obtained Th is it is pos ible to make a new va iety of s l ca wh ch unl ke the us i l on r acts with hydrofluoric acid at ery ma k lly redu d rate Undoubtedly high p es ure–h gh temperature chem stry is de tined to b come one of the most imp rtant a eas of re earch i norganic hemi try

For m ny s l d tate de ce it is of the great st importan e to have ve y pure mate ial or material w th j st the orr t amount of impurity For tran tors l is of the g e t t mp tanc to e c r ilico co tai in tl e rder of a few parts per bill on of impur ti This i commonly achi ed by a c mb nati n of ch m l and phy cal procedu e in l d ng z e m lt ng Th j i parat on of ıltra pu e no g nıc compound s al o ital in the p ep a at on f lum escent and pho phore c nt mate-ials

Geochemical aspects Many of the sy th ti p c d es carried ut at h gh temp rat r s and pres s ha e c n id rable ntere t n ge che n s-try P rhaps th ea l est i n gani chemi t y was p a ticed in c nne ti n w th mi eral gy Mineral synthes n the p eps at on of norga ic c m po d d nt al w th tho e found n natu e are i cr a ingly o upy g the atte ti n f the ıno gan chemi t N t only is this of ci nt fic imp r tance i e pla ng the sequen e f ch m cal r ac ti ns nd c nd t ns re p ibl for th format on f the mine al n natu but ma y miner ls and gem of indu t al impo tance an n w be synthe d om on the l rge ind tr l cal d amond ruby appl i n quartz, or ndum E ther h gh t m p tu e rea t o o hyd th rmal r acti ns ca ried out in water at h gh temp ture and p e a e empl yed W th th ad ent f ltrah h pre e quipm nt t n w bec mes f a ble t t dy ch m al rea tio s unde nd tio approximat i g tl m y m le bel w th e rth s urf ce Su h tudies can surely be e pected to make m jo contr but n to the u der t nd g of geochemi l phenom n Se HIGH PRESSURE PHENOMENA.

Nuclear technology Th d elopm nt of cle t chn logy h pr vided a great mpetus to inor gan c hem try The eff rts of the in rgan chem i t ha e be n indi pen able to th ce ful ut li zation f nucle ergy The d very of the tran uran um elem ts one f the out tand gly imp rt t ent n h m cal sci e has pro d d a h t of problem It has been n ce ary to ex pl re in d i l the ch m try of the t nide le m nt in o de to d termine how the e new le-ment we i be inco p rat d i to the per odic tabl and fo the immed ate p t al purpo e of

devising suitable methods for the isolation and purification of plutonium and other transuranic elements The development of solvent extraction procedures for separating the actinide elements has been applied to other inorgani ions and has had widespread repercussions in inorganic chemistry Nuclear technology has also provided the impetus for the development of other separations procedures for example the separation of zirconium and haf nium and of the rare earth elements from each other and has generally served to reinforce the tra ditional interest of the inorganic chemi t in separa tions procedures

Applications in organic chemistry Before leav ing the discussion of these aspects of inorganic chemistry it may be instructive to point out one of its interesting by products Many of the most im portant advances in organic chemistry that have occurred since 1900 have re ulted from the intro duction of inorganic substances as reagents The in troduction of magnesium metal gave rise to the vast corpus of Grignard chemistry and of metal car bonyls to Reppe chemistry Other inorganic sub stances that have found important u ■ in organic chemistry are elenium for dehydrogenation reac tions lead tetraacetate for elective oxidation aluminum chloride as a catalyst for alkylation acylation and ring closure reactions anhydrous hydro_en fluoride for diazotization nitrati n sul fonation and isomerization reactions and mo t recently lithium aluminum hydride for selecti e reduction reactions Within a few years of its di covery some 1500 research papers were pul li hed on the applicability of lithium aluminum hydride to organic syntheses Among the host of inorganic compounds there must be many of great utility in organic syntheses

THEORETICAL INORGANIC CHEMISTRY

For a long time inorganic chemi try was e en tially preparative and descriptive but modern in organic chemi try frequently ■ difficult t differen tiate from physical chemistry or chemical phy ics The modern inorganic chemist ha an inten e inter ■ t in the structure of chemical compounds From a knowledge of the interat mic distance and other geometrical data valuable inferences may often l e drawn regarding the nature of the chemical bond ing involved and thus of chemical l eha ior All modern methods of tructure determinati n are em ployed Electron diffracti n x ray and neutron dif fraction infrared and ultraviolet al orpti n spec troscopy magnetic usceptibility measurements and nuclear and electron paramagnetic re onance are all employed for structure determi ati n For the ca e of n nstoichiometric c mpou d Gil l s pl a e rule studie x ray cry tallography and vari o i electrical mea urements f nd particular appli cati n for structural inve tigation The tudy of ch mical tructure has hed new light n m ny cla ical p r l lem For example elucidati n of the tru ture of pho pl oru con pound l a provided a firm f undation f r th n w chemi try of phosphorus now in the proce s of formulation An other classical structural problem has been that of the boron hydrides Simple valence bond theory wa inadequate to account for the forces holding the molecule together Recently it has been concluded that a new type of chemical bonding called a three center bond becau e two hydrogen atoms and a boron atom are held together as a unit is crucial in the structure of the boron hydrides

Bonding There ■ an intimate relation between structural studie and a detailed interpretation of chemical bonding A knowledge of the geometry of the molecule contributes to an under tanding of the forces involved in chemical bonding and con versely for certain cla ses of compound a kno l edge of the nature of the chemical bonding helps define the geometry of the ubstances In addition to the cla sical forms of valence crystal field or ligand field theory has l ecome very important ■ theoretical inorganic chemistry It is es entially an extension of the electrostatic theory of chemical force Ba ed on molecular orbital theory cry tal field theory con iders the effect of the local elec tric field on the energy levels of the various orbitals involved in chemical bonding For certain combi nations of field and orbitals splitting of the energy levels occurs and certain orbitals gain an extra en ergy of tabilization The effect of the cry tal (or ligand) field may be reflected in a di tortion of the molecule so that crystal field theory is becoming increasingly important in the interpretation of structural distortions found in the crystal truc ture of olids *See* CHEMICAL BINDING

One of the most important area in which crys tal field theory ■ l eing applied is in the study of coordination compound Cry tal field theory has enjoyed considerable succe in predicting the ■ l ility of complexes of different metals with differ ent li_and in explaining magnetic and ab orption pectra of complex compounds and in predicting rates and mechanism of reaction of complex com p und The stereochemi try of co rdination compound is a cla ical preoccupation of the in organic chemist and the tudy of the complex co ordination compounds of the tran ition elements has been one of the mo t active and fruitful areas of endeavor in chemical re earch ince 1900 The fact rs invol ed in the relative tal ility of the large number of coordination compounds formed from the various tran ition elements ha occupied the attention of many inorganic chemi t and de pite the great advances which ha e l een made in recent years particularly l y the application f cry tal f eld the ry the prol lems are still far from ettle l Re earch into the factors involved in the tereo chemi try tal ility and reaction of c ordinati n compound tl us continue as a leading acti ity of inorganic chemi t The implication of si ch rk extend far l ey nd the field of inorganic cl emi try l e au e f the importance of coordinati n pl en m ena in photo ynthe i re piration enzyme reac ti n chemoth rapy and other l i logical phenom ena

Reaction kinetics Th mecl a i m of in ganic r a t has n t t the pa t attr ted as m ch at t nt n as th tudy f rg nic reaction but thi i at n rap dly being r ct fed O ganic eac t g ner lly n oc ed with the kel t of the m l c le r mai ing i ta t In rga i gas-pha e r t s ar usually chara teri ed I y a c mplete di r pt n of m lecul r tru tu e f llo d I y re rg zati n t I rm the p od ct of th react on G s-pl e eaction are m e mpl c ted tl a the u a l rgan rea t o a d d p te e n id rall tudy much r ma s t b don De pite th im p t n f o idati n redu t o rea t n and t n it n l me t whi h re ch racte ized by a m lt pl c ty f ox datio tates the m chani m of l tr tr fer r act o in olut n has nly re c ntly be m tl ubject f r s i e tigati n Th res lt of r i d ate that d ct el ct n trans-f r from o o t n th r mp ball e nt th t th i n f r f l t n b tw en ation i med at d I y a o s p es nt which act as b dg ng gr p and that the s l ent part c pates in the l ctr t an f ct o The mechan m of sol d i t a t o h al l ome an mportant fi ld f re a ch nd ther i ry rea on t bel eve th t th tudy f r t on mech ni ms i ino gan c ch m try will b on f gre t mp rtanc i the f tu e devel pment f i g h m try

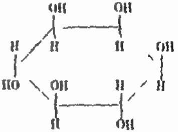
Th tu e l n in lut n mportant n the m p etat f tl p p rties f l i n f l e c lyt nd t n k net Con q ntly th t dy f of to i g ou ly p r ued M ny m thod r v i l le a d th e i lude p ct p^h t m t el t mot fo nd pola g aph me u eme t w ll a the by now l al phy l h m al pro ed s has ol b l ty m em t o e ha g a d l nt p rti n t d es Th bj t to ascert n the ex t nt f t t n f th m t l ion w th th l e t a i h h p t ula ly p m t when h ghly t rged m t l i s l d nd w t r the l nt The xtent f nt t b twe n ati n nd n n th t m y t e p esent mi st also b d t rm n d P d g n th s way t is p s ibl t pe fy the k l nd am t f ach n c sp es p e t n th l t A kn wledg l th on p mp n t p rt l lyi the i te p et ti f t tud rd th t dy f l t n n f nd ment l t fi th r p g th f ld f a t n me h n ms l m th f g g t can l n th t the f f rt of the p pa t d the th or ti l nor g n h mi t ppl me t th th th c m p nd pr pa ed by th sy th t c gan c chemi t p d th p bl ms f the th t al g n h mi t wl e th t rp t t and on l o f th et al hem try f eq e tly p d the mper f n w d mp d ynth t pr e d r

APPLIED INORGANIC CHEMISTRY

Th p od t n f g n heme l h s t th h m l d t y a d th l g l pro-duction f in rgan h mical s i h a lf ric a id amm nia hl rine s la a h pl l r i and other hea y inorganic h m al pr i les and s p n al i t ri g material f r m ny ind i tries In a ld t n t tl t nnage prod icti n of m rgani ch mical tl e gla ceram cem nt f rtil r r and m tall irgi al ind i tri are es enti ll in r gani ch m try applied n th l rg scale Many f thes indu trie are still tra l ti l in nat ire l t it i alt geth r l kely th t m d rn i rgani ch mi try w ll make i crea ingly sul tantial c n trib t on to the l t re es l ti n l i rgani technol gy S e CHEMICAL STRUCTURES CHEMISTRY HIGH PRESSURE PRO ESS MAGNETOCHEMISTRY ORGA IC CHEMISTRY PERIODIC TABLE PHYS I AL CHEMISTRY [J J K]

Inositol

A it min wh h pr nt l of l tr and l rma tit s in an mal Th re are nine stereoisom r f hexahydroc l h xan l wh h nly n ha l o l g al importa e It i alled i itol r myo-in it l and i a ry tall e wat r lul le al l l Its tr t r l f m la is shown l el w



Ino t l

It is est m ted by m cr l i l g l m thod V r tu lly n th ng i kn wn f it fun ti n n nzym sy t m It n be m tabol ed a a a l hydrat Ia ed it is f und a the h x ph pl ri e ter phyt c d Th phyt a d f wh l wh at i f nutritio l import e becau m ml n tl d t ry c l um de a i g it a ail l l t Besides bei g es nt l f the gr wth f m roo gani m no t l b s h e h wn t f n ary for mi a d rats und r som c nd t on In itol d f ien y n odent h s l n h e t e ed l y p g owth a d ha l s Ino itol i c n d ed a l p tr pi agent, e n n mber f exp r m nt l nd t on t p ev t fatty l er \ o ider l l m t l n t l ynthes ed by nt t nal l a t ia Th e s no evid ce f a huma di ta n it l eq ment S e CARBOHYDRATE LIPID VITAMI [M N G]

Industrial production I s t l prod ed c m me lly fr m or te pwater wh h i by p od act f the w t mill ng of co n. I o i l o urs n o n te p wat r a d alt of t h aph ph t ste phyt d T ting th t pw t r w th l me yield a p p tat of crud c l um phyt t Th is t e d and bjected to h gh t mp a t r hyd ly inder p e r y ld ng n t l nd l um e d ph phate Th sol l l ph phat p pitat d l y ett al ati n th i m a d th

devising suitable methods for the isolation and purification of plutonium and other transuranic elements. The development of solvent extraction procedures for separating the actinide elements has been applied to other inorganic ions and has had widespread repercussions in inorganic chemistry. Nuclear technology has also provided the impetus for the development of other separations procedures, for example, the separation of zirconium and hafnium, and of the rare earth elements from each other, and has generally served to reinforce the traditional interest of the inorganic chemist in separations procedures.

Applications in organic chemistry. Before leaving the discussion of these aspects of inorganic chemistry, it may be instructive to point out one of its interesting by-products. Many of the most important advances in organic chemistry that have occurred since 1900 have resulted from the introduction of inorganic substances as reagents. The introduction of magnesium metal gave rise to the vast corpus of Grignard chemistry, and of metal carbonyls to Reppe chemistry. Other inorganic substances that have found important use in organic chemistry are selenium, for dehydrogenation reactions; lead tetraacetate, for selective oxidations; aluminum chloride, as a catalyst for alkylation, acylation, and ring closure reactions; anhydrous hydrogen fluoride, for diazotization, nitration, sulfonation, and isomerization reactions; and, most recently, lithium aluminum hydride, for selective reduction reactions. Within a few years of its discovery some 1500 research papers were published on the applicability of lithium aluminum hydride to organic syntheses. Among the host of inorganic compounds there must be many of great utility in organic syntheses.

THEORETICAL INORGANIC CHEMISTRY

For a long time inorganic chemistry was essentially preparative and descriptive, but modern inorganic chemistry frequently is difficult to differentiate from physical chemistry or chemical physics. The modern inorganic chemist has an intense interest in the structure of chemical compounds. From a knowledge of the interatomic distance and other geometrical data, valuable inferences may often be drawn regarding the nature of the chemical bonding involved and thus of chemical behavior. All modern methods of structure determination are employed. Electron diffraction, x-ray and neutron diffraction, infrared and ultraviolet absorption spectroscopy, magnetic susceptibility measurements, and nuclear and electron paramagnetic resonance are all employed for structure determination. For the case of nonstoichiometric compounds, Gibbs phase rule studies, x-ray crystallography, and various electrical measurements find particular application for structural investigations. The study of chemical structure has shed new light on many classical problems. For example, elucidation of the structures of phosphorus compounds has provided a firm foundation for the new chemistry of phosphorus now in the process of formulation. Another classical structural problem has been that of the boron hydrides. Simple valence bond theory was inadequate to account for the forces holding the molecule together. Recently it has been concluded that a new type of chemical bonding, called a three-center bond because two hydrogen atoms and a boron atom are held together as a unit, is crucial in the structure of the boron hydrides.

Bonding. There is an intimate relation between structural studies and a detailed interpretation of chemical bonding. A knowledge of the geometry of the molecule contributes to an understanding of the forces involved in chemical bonding, and conversely, for certain classes of compounds, a knowledge of the nature of the chemical bonding helps define the geometry of the substances. In addition to the classical forms of valence, crystal field or ligand field theory has become very important in theoretical inorganic chemistry. It is essentially an extension of the electrostatic theory of chemical forces. Based on molecular orbital theory, crystal field theory considers the effect of the local electric field on the energy levels of the various orbitals involved in chemical bonding. For certain combinations of field and orbital, splitting of the energy levels occurs, and certain orbitals gain an extra energy of stabilization. The effect of the crystal (or ligand) field may be reflected in a distortion of the molecule, so that crystal field theory is becoming increasingly important in the interpretation of structural distortions found in the crystal structure of solids. *See* CHEMICAL BINDING.

One of the most important areas in which crystal field theory is being applied is in the study of coordination compounds. Crystal field theory has enjoyed considerable success in predicting the stability of complexes of different metals with different ligands, in explaining magnetic and absorption spectra of complex compounds, and in predicting rates and mechanisms of reaction of complex compounds. The stereochemistry of coordination compounds is a classical preoccupation of the inorganic chemist, and the study of the complex coordination compounds of the transition elements has been one of the most active and fruitful areas of endeavor in chemical research since 1900. The factors involved in the relative stability of the large number of coordination compounds formed from the various transition elements has occupied the attention of many inorganic chemists, and despite the great advances which have been made in recent years, particularly by the application of crystal field theory, the problems are still far from settled. Research into the factors involved in the stereochemistry, stability, and reactions of coordination compounds, the continue as a leading activity of inorganic chemists. The implications of such work extend far beyond the field of inorganic chemistry because of the importance of coordination phenomena in photosynthesis, respiration, enzyme reactions, chemotherapy, and other biological phenomena.

but n t in the f ear d men o s f the hard parts At th molt the old c ticle i h d and the n w ex p nd and ha den w th m ho ir or le s In pr m t wingless in ects there are only l ght cha ges in form at e ch m lt In othe s such as the gra s h ppe and r che the dult d ff r f om the im mature tages r nymphs by pos e ng wings and fully formed repr ducti e gans In the higher in sects, x mpl fied by the butterflies bees wa ps ants fl e and beetle growth takes place during a e ies f larval st special zed for feed ng D ing the inact pup l tage the body f th adult diff r ntiat at the expen e of d ge erating larval ti su and f t. T s es of the adult are lready de t rmi d the egg and an be dentified in the l rva as latively slow grow ng imag nal d sks

Prol feration d diffe e t at n of larval or nym ph l t s u precede each molt xcept the last Acti t on of latent adult t ssue take place at the end of th la t larval stage and conti ues dur ng the pup l st g Thes p oces es and the e suing molts a e t m l ted by h rmone (ecdy one) riod ally r le d f om th pr thorac glands Secre ti n f the protho a c gla d is in tiated by ho m e p du ed by ne r ee et ry c lls in the b The p oth rac c horm n ets on larval nd ad lt t sue alik b t du ng nymphal and l rval t ge its act o n adult t s e is largely sup pre sed by a ju enil h rm (neoten n) om g f m th rpu all tum a mall gland n ar the b a n At pup t n a decr a e in neote n perm ts f ll a t o f the pr th c hormo e on adult tis s es within the l rv Thu extra molts nd abnor m ll la ge ts n be produced by tr pl nt g rpo a allat fr m arlier t g Con ers ly pr m tu p pat o and dwa f dults e ult f om exc s o of th c pora all t f m y g larvae

D pau e a c d u n in wh ch d el pme t st p n at rmal temp e at e oc ur n in ny i cts th t o rw ter n mmatur tages Development a b in tiat d by e po ng d pa si g p p e t a p od of old d then rewarm ng th m Th e t n nt a t at th bra n and the protho ic gland syst m Th rea ti ati e ses a gre t in a the zymes c cerned with o d t ve m t bol m nd w th certa n n rv fun ti ns

Cuticle The epiderm l ell t a sem rigid ll l r t le th t ers all extern l p rts and l l the respi t ry tem a d the f e nd hindguts The c ti le erves a truct al skelet n f b ally ylind l fo m nd ll skel t l m s les p ll n ts nne f e At jo t the cuticl t m s th n d fle bl

Th structur l comp ent f th ticl re p o te n nd hiti a ompl x of p ly c tylgl cos m e Th h rden d d rk i g of cuticl due i d t on of tyr s e and oth r ph nols to qu n n s wh h f m o s br dg w th pr t n Oth r uti le ol rs may b d e t pt ne uth nes and a t l of plant rigin and t d s nt eff ts r ated by fi e sculpt i g f the cut cle urf ce Th h tin c t cl is tr e ed by fin p re als, ll w g w xy o o ly ec t ns t re ch t f nd p d t nto a thin h d ophob layer A very thin cement layer i found out ide this on mo t in ect cuticles These layers play an important part in limiting water lo l y evapora t on The eff cti ene s of many oil s lul le in ecti cides uch as DDT depend in part on solubil ty in the wax layer of the cuticle (see INSECTICIDE)

Growth is l mited l y the rig d ty of the cuticle Before m ltin the deeper layers of the ld ct ticle are di lved l y en ymes and a new pliable cuticle is la d down beneath it Finally a m lting fluid i ecr ted l etween the cuticles and ga accumul t in the gut Thi ca es an ncrea e in body b lk which spl t the remains of th old cuticle along the back Ca is retained in the gut unt l the new cuticle ha dens

The mirig d cuticular ex keleton has been a maj r factor in determin ng the succe s (number of pecies en ironments occupied) and l mitat ons (body size) of the group Insecta

SYSTEM PHYSIOLOGY

Respiration *Opening* r pir cles the ides of erta n body egments c nnect with a system of a r tube the tra heae that l ranch t every part of the body *Tracheae are ofte* enlarged i to air s l te nal cutic lar ridges (taenid a) pre ent collapse of the tra heae and the r terminal l ranches the tra heole The tracheoles end in submicro op c branches cl e to or within all body cell At certain times the trach al system may b filled with fl id whi h can be partially or mpletely withdrawn int the tis ues Th s proces ha not b en fully explained

Exch ge of oxygen and carbon d ide may oc cur partly or entirely thr ugh the body ut le par ticula ly n m ll in ects a d egg r by pa si e d ffu n thr ugh th sp racle-tracheal sy tem In l rge n e ts or d ri g periods f mu cular a ti ty passi e diffu n s augm nted by acti e entilati n The t acheal tubes or a r sacs rhythmically ompres ed by pump ng m vem nts of th abdomen r by contract on f the mus les dur ng locom t n fl ght Gas flow in th ma n tracheal trunk may be egulated by sp r ul r valve sensiti e to ch nge in yg or bo d x de pre ure The final g se us exch nge appe r to be accomplished by d ff n th gh t acheal walls to the body cells

Aquat in ts that rema n cont nuously ub merged ha e a closed gas filled trach al system int wh ch s s d ffus thr ugh gills D ving in e ct return p riod ally to th rface to re ew a film of r carried n the ha hydrophob c ut cle o u der th w ng a es Oth aquatic or end para s tic fo m ha p racul r siphon th t b eak the surf c film

M ny i ect t l ate l w oxygen tens on for long p iod Th blood has l ttl n p at ry functi n except in the l rva of om m dges h ing m t gn nt w ter Th blo d f th l rv e con t i hem gl bin in s lution. Most sect are in ens ti e t ca bon monoxide owing t the absen e of hemoglob n Exc pt n diap u i g pupae cya ide s s ally po s us b ca e of th presenc f a cytoch ome sy t m *See* RESPIRATORY PIG TENTS

clarified solution ■ concentrated until inositol crys tallizes Purification is accomplished by carbon treatment and recrystallization

In spite of its seeming simplicity the process is expensive because product yield is extremely small in comparison to total material handled in the proc ess [N E A]

Insect control biological

Biological control has been technically defined as the action of parasites predators or pathogens on individuals of a host or prey population resulting in premature death or reduced fecundity Some au thorities would limit the meaning of the term to man s use of organisms to control other organisms The term microbial control is frequently used to indicate that type of biological control in which mi croorganisms exert the control and is one of the applied phases of the field of insect pathology Al though all manner of living organisms are included in these concepts most of the present knowledge in the field of biological control is based on the effects of parasites predators and pathogens on small vertebrates weeds and insects in particular on the latter Although the role of biotic factors in the suppression and regulation of in ect populations was perceived during the nineteenth century a broader appreciation of the potentialities of the role and use of biotic agents has been a twentieth century de elopment

In nature beneficial insects and mi roorganisms are constantly taking their toll of pest populations In an increasing number of instances man has learned to introduce or manipulate biological con trol agents in such a manner as to reduce the den sity of a pest population to a point below that at which economic injury to man s interest occurs Classic examples include the introduction into Cal ifornia of the vedalia beetle from Australia to con trol the cottony cushion scale on citrus the intro duction of certain chrysomelid beetles into Australia and the United States to control St John s Wort or Klamath weed and the use of milky disease bac teria to control the Japanese beetle in the eastern United States An example of an unusual form of biological control is the relea ■ of male screw worm flies sterilized by x ray which mate with females that then lay infertile eggs

The basic principle of the biological method of controlling pests involves the knowledge that there exists in nature a balance between the pest and its enemies and that this balance may be altered or shifted intentionally in such a manner as to de crea e the numbers of the pest Pests are fre quently unintentionally brought into an area and enabled to flourish without being accompanied by their natural enemies Biological control scientists seek out u ually *in* the pest s native habitat the missing natural enemies and then introduce them into the recently invaded area

The injudicious use of chemical insecticides some times up ets the natural parasite-host balance thus permitting the pest to recur in destructive numbers or relati ely minor pests in the absence of or through the destruction of their natural enemies may become serious pe ts

In addition to their role as microbial control agents in nature or as introduced biotic agents en tomogenous microorganisms may also be u ed ■ microbial insecticides that is as spray or du ts. This method appears to be esp ecially fea ible with bacteria and viruses but similar ■ e of fungi pro tozoa and nematodes may also be po sible Or dinarily resistant stages (spores) of the e mi croorganisms are used when dis eminating them Microorganisms may al o be introduced into su ceptible host populations where they become es tablished and remain active for long period of time They may also be used in combination with chemical insecticides and with parasites and predators

The principal advantages of biological control methods is that they do not leave toxic re idues and they may be more lasting in their beneficial effects Furthermore microbial control agents not only are nontoxic to man animals and plant but usually do not harm the parasites and predators of the pest or beneficial insects such as the honey bee *See* ENTOMOLOGY ECONOMIC INSECTICIDE [E A S T]

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Insect physiology

The study of the functional properties of insect tis sues and organs The adaptations enabling in ects to live on land are oft n strikingly different from those found in other animal groups such as the higher vertebrates Accordingly insect physiology makes a comparison of physiologic adaptations in insects which have analogous functions ■ other forms Insects because of their diversity abun dance and wide distribution exert great influence on the general character of life on land Insect physiology therefore contributes to the broad study of terrestrial ecology Insects assume eco nomic importance as crop pollinators disea e vec tors and pests (*see* ENTOMOLOGY ECONOMIC) In sect physiology is also concerned with the control of certain insect species and with the mod of ac tion of insecticides In spite of their specializa tion insects have basic physiologic mechanisms common to most forms of life Some of these mech ani ms becau e of the unique manner in which they are displayed in the insects are especially amena ble to exp rimentation

DEVELOPMENT AND GROWTH

Development Fertilization ■ internal Unferti lized eggs normally d elop into males ■ many ants bees and wasps and into females ■ summer generations of aphids Eggs le elop externally in most cases Early cleavage in the egg ■ limited to *the nuclei*

Postembryonic gr wth is discontinuous being in terrupted by 3–8 or more molt During each inter m ■ period the in ect feeds gains in weight

Regulation and excretion Terre t al insects c n erve the r b dy w ter by h i g a watertight c t le a d by ab rl ng m t of the w ter befo e ıding ut ne and fe es Some beetl s live on dry food u h a t red g a n nd wood under c nd t s whe e free w t r ıs n t a ilable for drinking Th y c erve as th r body flu d tl e water f rmed m e of the e d p od t f o datı e m t bolı m Insect hav a flu d d et of pla t ju c o blood xcrete la g am nts of wate y ur ne o ther fl d l ke the h ne dew of phid I fre l wat r ın ect the m t c t nd ncy to gain water ı lım ted by l w utı lar perme b l ty nd by c etıon of d l te u e Salt l s n f h w t r ı offset by lt t ke ı the food by a t alt r t nt on and by salt upt ke thr ugh anal pap llae s een ın mos q t larva

Land n ect a e abl to tole a on derabl blood l des cat on blood d l t on and ch nges ın th r latı onc ntratı ns of blood so d m and pot ıum N rves a d mu cle depe d f r no mal fu ct upon a fairly n tant r t o of these s n th n nd ng flu d l n ects these tı ues e p te ted t fluct at s ın th bl d mp t by th Malp gh an tube nd rectal gl d y tem nd by p c l heath ur o d g g ngl d erv Oth r r gulatı g mech m e st ll t be di ve ed

Th n tr ge wa te f l nd ı t ı elımı ated m ly the f m of u c acıd by the Malpighian tub A ıable umber f these l ng fı e ı bes pe s to th h dgut the l d ends ly g f e among other org ns ın the l ody ca ıty Flu d pa from the blood nt tl e Malpıght n tubes and ı con entrated ın tl e l w r parts of tl e tı be an l ın th hındgut Tl e urıne con t maınly of a pa te or p wde of urı acıd cry tal Exc alt l k pota ıum from plant ju ces r odıum fr m erte brate l lood ıngested durıng feedı g are excreted ın the ame manner

In ects l ke the bl wfly larvae lı ıng ın fluıd or m flu d en ır nment el m nate some of theır nı tr g n wa t a amm nıa Salt f amm nıa urate ph ph tes arbonates and p gm nt d rı ed fr m th f d m y be t ed ın the fat l dy and ther t ues f r p rt f the larval r pupal l f (t rage ex r t n) On mergence f tl ad lt th e m ta bol c e d pr d ıct may be l mınated ın the fır t bow l m vement (m nı m) or they may be ıncor porated as p gment ınt the cut le r the scales f b tte fly wı g S EXCRETION

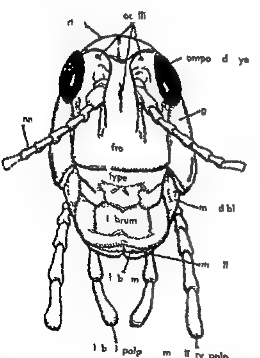
RECEPTORS AND RECEPTION

Vision Many adult ın ect po e s tw kınd f ual org n mpound eye and ocell In bo l typ of eye th l ght en ıtı e regı n c n ı t of a mbe f ell g o ps (etın lae) e ch c ntaınıng 2–8 *ph to ec pto cell* Th ph t recepter cell f e ch et nula are arranged r dı lly wıth tl r n tral lıght sens tı e portı n (rhabd m re) eıther lyı g ın el c nta t o f g t form a tral stru t the rh bd me

In *ompound* y e ch ret nula ı pr ıded with s p rate opt al y tem n ı tıng f a c n x orneal facet of cutıcl nd an underlyıng cry tal lı e o e These ı ı al un ı (*mm t dıa*) are par t ally e mplet ly l lded from o e an tl r by *l ght abso bıng* p gm nt s that ea h rhabd me ıs mo t eff ı el stım lated l y l ght enterıng the *mmat dıum* w th n a f w deg e f ıt l g a ı The h ld ng p gm nt are oft n capabl of actı e mo ment a d m y l e w thd awn u der c nd t o s f l w l ght nt n ıty so that l ght ent ı g an om m t dı m m each ne ghbo ı g u ı a well

Each mmat d um a ı ual un t f sm ll vı ual fı ld (bout 8) nd has a res l ıng p wer l mıted by the ımber f th bd m es (8 or less) Ea h c mp und e *may* co ta n fr m a few d zen t m ny thou a d of mmat d a ar nged r dıally ın e rr y o e ng ın some c s a ol d ngle gr ater than 180 Thu *wıth both* comp nd eyes n n e t e urı y m t f th *ımmed* ate en ı n m t mult eou ly wıth ut the n ed for eye or h ad m *ement*

The a gle b tw e the x f adj ent omma t d a va dıff rent et pecıes and d ffer e t eg ns of the *m eye* Small mmatıd l n gl s enc nt ed on the fr nt of th ey ın pr datory n t u h as the p ayı g m t s and dr gonfly I reg f th e f th bl wfly wh th s a l bout I th ı ual field f each mm t d um ı about 8 A po t wıth n th s field n be re l ed by l ght fallı g o o e other of the 8 habdom e but ı th ı al fields of n ghbo ı g m at d a mu t e l p th p nt may



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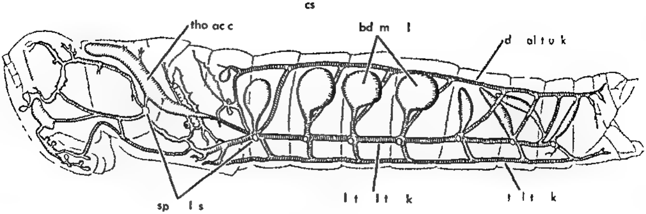


Fig 1 Grasshopper respiratory system showing spiracles tracheal t ks and a r sacs of the l ft s de (From T I Sto er a d R L Us ger General Zoology 3d ed McGraw H ll 1957)

Digestion and nutrition There is little of nutritive value that is not attacked by insects Diets range from fluids such as plant juice and blood through conventional animal and vegetable foods to cellulose wax and wool The digestive tract is degenerate in the adults of some species in which feeding is limited to the immature stages Mouth part vary greatly with diet (*see* INSECTA)

Conventional digestive enzymes are produced by the alivary glands which ecrete silk in some species and by the midgut epithelium Mucus is absent In many ins cts the gut contents are enclosed in a thin chitinous sac the peritrophic membrane which is continuously secreted by the midgut Products of digestion diffuse through the peritrophic membrane before absorption by the gut epithelium The hindgut absorbs water from the digestive waste and plays an active part in metabolism and regulation It is also u ed as a propulsive and respiratory organ in dragonfly larvae which draw water in through the anu and then force it out again

Keratin the protein of wool and feathers is digested by the larvae of some beetles and moth The disulfide bonds of keratin are changed to sulfhydryl group by strongly reducing conditions in the mid gut Beeswax is the normal diet of larvae of the wax moth Symbiotic bacteria as well as enzyme se reted by the gut may play some part in its dige tion Wood dige tion is accompli hed in termites and some roaches by symbiotic bacteria and protozoa always present in the gut

In spite of their varied and often unusual diet the nutritional requirement of in ects are fairly con enti nal Ten amino acid the B vitamin complex and choline are es ntial for gr wtl F ential nutrient lacking in the diet are often ynthe ized by symbiotic microorganism Adult flies may exi t for long period on sugar al n lut n egg pr luc tion i p il le The fat body i tl e main t rage site f r nutriti e materials

Symbiotes A number of in ects harl or microorgani m witl in or among the cells f pe ializ d tissues as well as within the cavity of the gut Tl e e syml iotes include protozoa fungi yea t lacteri and lacterialike organi m In s me ca e micro organi m apj ear to be e ential to the life of tl eir insect host as in the termites with their inte tinal protozoans In others they contril ute to host nutrition and growth by increasing the availability of nutritional factors such as certain vitamins Still other insects show no obvious defects when depri ed of their symbiotes

Certain bacterialike organisms are cultured within specific cells grouped in a large organ the mycetome or scattered throughout the fat l ody Infection of the next ho t generation by these intracellular symbiotes may be acc mpli hed by migration of certain of the host cells to the walls of the ovary where the syml iotes are relea ed and penetrate the developing egg cells Intestinal syml iotes may be picked up when the host in ect feeds on contaminated food In other ca es the eggs of the host bec me contaminated at the time of o ipo i tion

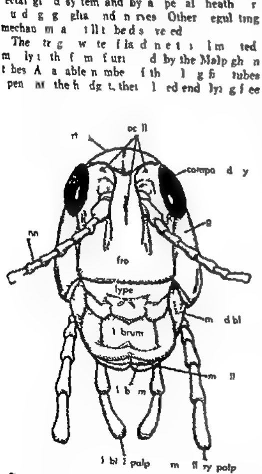
Circulation The blood is propelled forward at low pre sure by a dorsal heart It i di charged into the body cavity and filters back to tl e heart through spaces between organ and ti ue Acce sory hearts may promote the blood flow in elongate organs such as antennae legs and wing Since the blood has little or no re piratory function the circulation may l e stopped for h urs with ut untoward effects The heart rhythm is prol al ly neur genic as in other arthr p ds This means that the l eat originates in the activity of ner e cells in the heart wall from which nerve impul e are tran mitte l to the striated heart muscle In some larvae the direction of the heartl eat i re er ed at certain tim

Tl e l l d is mmonly c l rle yellowi h or green Bl l ell are varial l in form and numl ers h w phago ytic proj ertie an l may aggregate during l l l l tting The o moti j re ure f bloo l varie wid ly in d fferent j cie and under different n liti n Tl e dium j ta ium rati range from 10 r m r in carni i in t and in land vert brat t le s than l i ii y l erli orous form such as the ilkw rm l e ie Tl pr tein content i simil r to tl at f rt l rate l l d altl ougl the amin a i l c it nt nt n i l 50 time higl r The i ric acid c nt nt i l p ii nally l igh Tl e maj r arl hy lr t i tr l l a n nre lucing sugar Se CIRCULATION

Regulation and excretion Terrestr l insects c n erve the body water by havi g a w tert ght c t cl rdly r b orb g mo t of the water before id ng u ne and f e Some beetles l n on dry food u h a tored gra n a d wood und r ndi t n wh m f ee w ter i not a ilal l fo drink ng Th y n rv a th r body flu d the water f rm d n ne f tl e e d pr duct of idat e metab l m I se ts hav ng n flu d d et of plant jui e o blood n r te l ge am unts of watery u ine or other fluid l ke the ho eydew of aphid In fre h wat r i e ts th o m t t den y t ga n water l mited by low ut cular p rm b l ty and by e er t n f di l t r ne Salt l ss n fr h water i off et by alt nt ke i th food by act e salt r tent n and by s lt pt k th ugh nal p pill e a s n n mos-qu t l rva

La d n e t a able to tolerate cons derable blood l s r de i cat n blood d luti n and hanges i th elat e n entr t ns of blood o-d um d p t s um Nerv s nd m cles d pend f n) m l fu t on up n a fa rly c n tant at o f these n n the und g fluid I in ects the e t es r pr te t d ga t flu tuati ns n th bl d mp t o by th Malp gh an tube and ectal gl d sy tem and by a pe al heath r u d g g glia nd n rves Other egul ting mechan m a t ll t be d s ve ed

The tr g w te f la d n e t s l m ted m ly i th f m f uri d by the Malp gh n t bes A a able n mbe f th l g fi tubes pen nt the h dg t, thei l ed end ly g f ee



Fg 2 G h pp f t w f th h d (F m T (St d R L U g G l Z l gy 3d d McG w-H ll 1957)

am ng other organs in the body ca ity Fluid pa es from the bl od into the Malpighian tubes and i co ntrated in tl e l wer part of the t ibes and in the hindgut Th irine c n t mainly of a pa te or powder f uric a d cry t l Faces alt l ke pota s um f om plant j uces n odi m fr m verte-brate blood ngested dur ng feeding are excreted in the same manner

In e ts l ke the H fly larvae li ing in fluid or sem fli d en ir nment el minate some of th ir ni ri g n wa te as amm nia Salt of amm ni urates ph ph te carbonate and pigments d ri d fr m the food may l t r d in th fat body an l otl er t ue for part of the larval r p ipal life (t rage xcreti) On em rg nc f the ad lt th e m ta bol end prod ct may be elim nated in the fir t bow l m ement (m ni im) or they may be in or porated s p gments int the ut cle or th cales of b tterfly wi gs S e Excretion

RECEPTORS AND RECEPTION

Vision M y ad lt in ect po es tw ki d f i ual organ mp und eyes and oc ll In both types f eye the l ght en ti e reg n con i t f a number f e ll group (ret nula) each c ntain ng 2–8 ph t rec pt ell The ph t erept r cell of e ch et nula are arranged adially w th th r c n tr l light se iti e p rti n (rhabdome e) e ther fi ng in cl e ont ct or fu ing t f rm a central t ucture the rh bd me

In compo d y s each t nula i p o i led with a pa at ptic l sy tem c si ting of a con ex rne l fa et f cut cle and an und rlying ry t l l ne con Thes al unit (mmat dia) a par t lly r c mpl tely h elded fr m ne an tl r l y l ght ab rbing pigm nt so th t a h rhabd me i mo t ffect el st mul ted by l ght enter ng the mmat d um w thin a f w degre f ts l ng axis Tl h ldi g t gme t re often capable of act e m seme t nd may be w thd awn under ond t on f low l ght i te ty so that light nt ri g an om m t d um ma ach n ighbo ng u t well

E ch omm t d m a su l unit f m ll isual fi ld (abo t 8) and h s a resol ng power l m ted by th umber f habdomer s (B o l) Each c mp d eye may c nta f m f w dozen to ma y th and of mmat dia rr n d rad all in nv ra e ing in m n ses a solid angl great r th n 180 Th w th both c mp u d eyes ect ca ry y m f th mmed ate en r ment m lta usly without the need f r eye or h d m ment

Th angle b tw n the axe of adjacent omma t di es n diff r t n ect pec s and in diffe nt r g of the ame ey Sm ll omm t d al n gle en u t red on th fr t of th ey n I edatory ect uch as the p yi g mant s and d g nfly l r g of the ye of th blowfly whe th ngl s ab t l th v ual fi ld of ea h mm t di m i ab ut 8 A po nt with th s fi ld c n be esol ed by light f ll ng n ne or other of the 8 h bd m b t s n the isual field of n ghb r ng mmat d must l p the po nt may

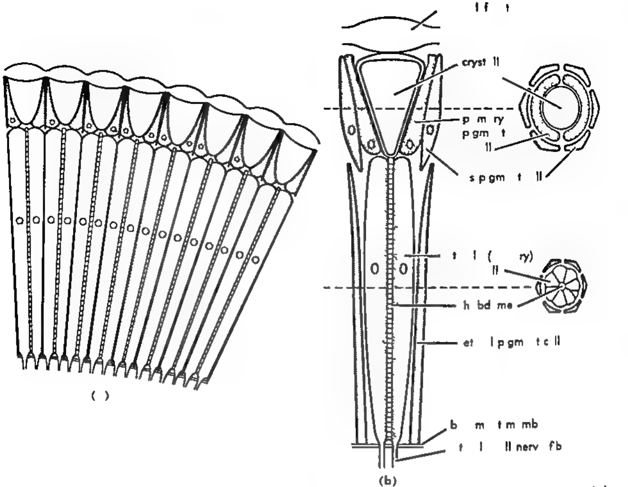


Fig 3 (a) Vert cal s ct on (d ag amm t c) of a port on f a compou d eye (b) Deta l f a s ngle ommat d um (Fr m R E Snodg a Pr c ples of I sect Morph logy M Graw H ll 1936)

also be re olved by rhabdomeres in adjacent om matidia Similarly the vi ual field covered by groups of ommatidia on the anterior aspects of the right and left compound eyes often overlap one another

Although the vi ual acuity or resolving power of the compound eye may depend in some degree upon ommatidial angle the overlapping of ommatidial fields indicates that the mechanism is certainly more complex than this Visual acuity of insects is inferior to that of man being about ⅟₆₀ in the honeybee and about ⅟₁₀₀₀ in the fruitfly Form per ception necessarily limited by visual acuity is man ife ted in activities uch as the learning or recog nition of foraging territory by honeybees wasps and dragonflies

Light energy reaching the rhabdomeres is ab orbed by a visual pigment In ome unknown way the photochemical reaction which attends absorp tion of light elicits electrical changes in the photo receptor cell bodies and in their axons (*see* PHOTO RECEPTION) The latter enter a complex y tem of optic ganglia which compri e a large p rtion of the brain

In ect eye re pond to wavelength from the near ultraviolet into the red Within thi broad range ome in ect eyes can di tingui h qualitati e differences among various wavelengths Beha ioral tudie how that honeybees recognize four col ors each repre enting a fairly wide range of wavelengths ultraviolet 300–400 millimicron (mμ) blue 400–480 mμ blue-green 480–500 mμ and yellow 500–650 mμ A ensory ba is for color ision has been demonstrated electro physiologically but not behaviorally in compound eyes of flies and cockroaches and in dor al ocelli of honeybees How widely color vision is di trib uted among in ects remains to be di co ered

In some of the species two or three dorsal ocelli occur which contain many retinulae grouped be neath a single undivided cornea They do not form image Their behavioral role is rather ob cure though in the cockroach they are in ol ed in the maintenance of a diurnal activity rhythm

Senses of taste and smell The e en es are con idered together since they both depend up n the act n of pecific chemicals The common dis tincti n between taste and mell bec mes difficult to make when aquatic an mal are considered The problem re olves ab ut the que ti n as to whether the chemical reaches the en e organ in the form of a gas r in olutio

The en e organ of tast are f ne cuticular hairs that ofte erve in add tion t uc receptors A minute receptive ar at the tip of each hair i reached by fine nerve proce e fr m one or more en e cell at its ba e Chem recepti e hair occur on the feet anten ae and o ipo it r as well a on

th m uthp rts (see CHEMORE EPTION) The n e f ta t ea ly d m n t at d by pp ly ng d ops f l uo to the f t of fl bees or b tterfl es If the in e t h b e dep d f water its m uth p rt w ll mmed t ly exte d to drink fr m the d p If t ha b en depri ed of food l ut has drunk water t t to th in ect will extend its m uth p tts nl f th d op e t n gar above a cer t n tr t n If in add t on to ugar the d op c tan alt ac d al h l or m ny the b- ta n th feed ng resp e may be blocked The ta t n t ty t a and many th r ub tan es h been te t d by thi method i in e t The s n t ty t alt nd oth r sub t nc s that re re- j ted has l been m a u ed by findi g th l w est c ent at on that will bl k the ffect of n c t at n of uga T te n it v ty va ies w d ly with the spe es t t d and th i d d als st t f ut t o l n ect n ti t ange to sug r lts a id d q n n o ers th t f hum n t i g and may xte d beyo d it By plac g dr p f sol t n o th tip f a gle ha it ha b fo nd th t ug r t m l t one of th e ll t t ba h le alt at m l t th r Th p e e c b e e f the feedi g r a t n appe r t depe d up n th relati e f eq ency of erve m pul es m ng f m thes tw types f s n cells lla s pon the i t rval n e a p ev s r l fn t may be abl to d ffe ent te betwee oth r types f ta t but l ttle i k own abo t thi

Lik m n ects a e able t d rim ate be- tw n tho s nd of diffe t od r Ma y od r t whi h i ect t in h gh d l ti n e od les t u F ta mal m th f ev r l pec e a e ted t fl ht t ty by the od r of a i g n femal m l m re d tant pw d On th th h nd b es d ma det t, nd f e th e f d ff t fl we i ab t the am d lu t n Th dev lopm t of t ep ll nts ba ed po the f t th t t d r p l n ects wh i h gh d lut n wh a they m y be n utral or tt a ti fa m d

P t ally n th ng k wn ab ut th phy lory f th olfa t y m h n m Olfa t ry ec j to s lor ted ef i fl n the a te n e a d t les er xt t n th m thp rt

A w te e e th abil ty t di r mi ate be twe n l t e h mid t es d t rient t w rd o way f m wat apo t a d t n e s well dev l ped i e ts Th n g l pp a t dep d th a t nna b t othing s k w bout is m h i m

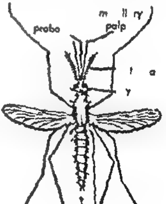
Touch posture sense and hearing All th e d pend p m ch n l t mul S n i t lo ed n a m g d ut l th y mu t h pec l m a f r d t ng mech al ha ges n th out w ld

Th f t b med t d by h i s a d pi e f ll es r ng th uti l of th l g ten e a d the eg n M ny f the e h s t ht ped so k t the cut le Wh the h b t a n c ll bel w th cut l t its b t m lated a d r f tv imp l es

s tra mitted inward t the segm ntal gangl n S me hair are so fine and l ghtly po ed tl at gen tle a r current or s nd vibrati n cau ben l ng ufficient t stim ilate Other are larg and t i t respo d ng o ly to impact with l t cles en oun te ed by the i e t

A n f th po t on of j rt of the l dy rela t e t each other i imp rtant in po t ire and in a n mber f a t n The po iti n f one l g j m relative to the n t of th head r lati e t tl body detected by mall gr p f fn h ir pl ed n th h ng so that they are bent in ary ing numb r a the j t t i fl d l art f thi po tural en e is determined l th f ce f gravity n the ta d ng i ect and f v the ten n fr m c n tracting m les Th e f r es cau e l nding or sh a i g tres es n the cut l tl t are d tected by group of ense ll placed bel w small ell pti al dome of tl n cut cl in the leg jo nt Th es am panifo m organ are al o f u d in fl es t the l a e of the halte e (sm ll rod surm unted l v kn bs) that replace th e ond p i of wing During flight the halte are il rated m h ndred l times per ec nd n a fixed pla e This g es the halteres th propert s of mall gyr pes Any tendency of th fly t de iat f m a tr ight flight p th cause tw t ng t nde cy at the halt re l e and timu lates the campan fo m organ Th resulting n n mpul e act ng th ugh the n rvo s t m and flight m cle rr t rrect th fl ght dev ati n

Oth r mecha i al n g n tak the f rm f fi e t u trand tt ched at ea h e d t the inn r s rface of the cuti le E ch t and c nta n a nse cell nd a e d ng (l ps) that app r t l stim lated by h at by cha ges in tl e dis t nce between the cuticula attachment In some



Fg 4 M sq t A ph l p h w g h lt (F m E O E g C lleg E tom l gy Ma m ll 1942)

insects these scolopophorous organs are especially modified for hearing The cuticle at one attachment becomes very thin and is exposed to air borne vibrations Specialized ears of this type are found on the legs of grasshoppers antennae of mosquitoes abdomen of cicadas and abdomen or thorax of certain moths They are sensitive to change in sound intensity but do not appear to discriminate changes in pitch The rate at which short sound pulses are repeated appears to be an important aspect of sound to insect ears Moths can detect sound frequencies of 100 kilocycles per second or more Insect ears serve to warn of a predator s approach (for example moths can hear the high pitched cries of hunting bats) or to locate the opposite sex The majority of insects are very sensitive to surface vibrations These are detected by fine sensory hairs and campaniform organs as well as by scolopophorous organs

SOUND AND LIGHT PRODUCTION

Sound production Insects make sounds by chewing on hard materials by vibration of wings or special membranes by rapid expulsion of gas from the tracheal system or digestive tract by tapping on the substrate with legs abdomen or head and by snapping or rubbing wings legs or other body parts against each other Many of these sounds are incidental to activities such as feeding or flight but an increasing number are being found to have communicative significance in insect behavior

The songs of grasshoppers crickets and cicadas are familiar to all Grasshoppers move a filelike structure on the leg against the edge of the wing crickets draw a scraper on one forewing o er a file on the other cicadas vibrate a pair of drumlike membranes on the abdomen by means of special mu cles The sounds produced are complex but consist generally of a series of pul es upon which is superimposed the higher re onant frequency of the vibrating organ

The pulse frequency pul e grouping pitch, damping of vibrator and other characteristics of these sounds are often highly species specific Some closely related forms can be more easily recognized by their songs than by any other means The informational content of these songs to other in ects depends on differences in pulse frequency and grouping but not on differences in pitch Male crickets have a repertoire of songs for different behavioral circumstances such as courtship or encounters with other males In most cases insect ongs erve to bring the sexes together or as part of the courting behavior

Sounds produced by the wingbeat or by vibration of the flight muscles are common and often intense In mosquitoes they play a part in ex recogniti n Bees produce a variety of sounds by vibrating their flight muscles Some of these may have behavioral significance Clicks caused by sudden movements of body segments and hissing sounds from escaping air may play some part in predator evasion

Light production Special photogenic organs occur in the larvae and adults of a number of beetles They are commonly found on the ventral surface of the abdomen beneath a transparent sheet of cuticle as in the common American fireflies *Photuris* and *Photinus* but they also occur on other parts of the body The light may be yellowish green bright green orange or red in color It can take the form of a steady glow of pulsations or of brief fla hes 0 075 ec in duration

Photogenic organs range from loose undifferentiated cells to an organize l tissue of clo ely packed photogenic cells backed by a whiti h re

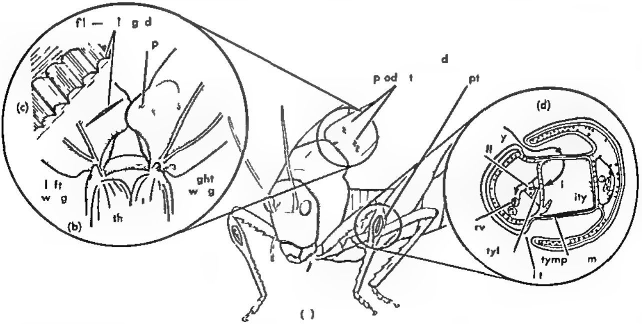


Fig 5 (a) Katyd d show ng locat o of st uctu fo sou d p oduct o a d rec pt o (b) U d su fac of fo ew gs w th f1 a d sc ap which p d c ds (c) Enla g d det l of f1e (d) C o s s ct o of fo l g show g so d receptor Path of s u d w es (b ken l) a d e imp l s (ol d arrow) (F m T I St r a d R L U g G l Z logy 3d ed McG aw H ll 1957)

fl ct ng l v r Th l tt r type char ct r t c of the fir fl e m nt n d ab e ha a r cf tra h al p ply As they appr ct the ph togemc cells the tra hea narr w nd b an h r t fine t a heol s t wh ch po nt th y re en mpa ed by tracheal d ell

Light i p oduced w th n th ph t gen c ll by th x dati f a l w molec lar w ight complex k o n as l iferin n the pr e c of an enzyme l fe a e (s BIOLUMINESCENCE) Th pr ductı n f fl h sappe r to l ntrolled thr gl the nerv u y t m At th prese t time it eem p b lle that nerv mpul e a t dir ctly n an enzyme c n t olled a ti n with n the photog n c c lls rather th ind rectly by regulat ng the xyge supply th gh al n the t a l eal e d c ll

At d k th mal of *Phott u* fly ab ut fla hing p nt n ly Th fem l w ngles a d fla h s only in r p e t th fl l of a by m l The fly ng m l t rns toward he fl h nd aft few f th ex ha g th y meet and m t Th mal d im te the f m l a wer ng fla h f om th fl he m d by oth r male it oc s x tly 2 ec ft h s gnal

MUSCULAR MOVEMENT AND FLIGHT

Muscle In t muscles r g r lly m lar t th e of t b tes e ept that th y e ert the p ll n th inn fa e f th c t ular exo k l t Ea h mu le made p f m lti cl t fiber e h c nt ng n mb s f p rallel r s tr ated my fib l The fi t u tu of the my fibr ls i m la t th t f d t at d m cl of ther an m l g ps. Sn th m el nd mot l l a n f k g ect T d a e l nt the mu le fib rs b g tta l d dir tly t the n s face f th t l t taw rd cuti la e t sions (pod es) A tw k f t d m l fl l se h ll w ga h as th gut he rt nd e p od tra t

M l fib f l g and m t tru k mu le a t b la f sm d 10–30 m r n (μ) nd m t r *A e t l o* ta a umb r f u l Ar d th s d l w of my fib il lo ed in the mu l fibe m mf G nt m t h dr (ar mes) r h dati n m a d t b t d m ng th my fib il O t d th m cle fiber m m b d m t m p n tr t ng th fib a t k f t h a d s

O t th mot r rv axo n h t all the fibe i m l T rm l br he f o ll f th a may l f d n th m mbr e at s t rv ly l 40–60 μ r the l ngth of the m cle fi be O e m t x n th f t fib s ppl m t ll f the mu l fib d n m re mp l n t g m a qu k p w l l tw t h O o m e l w m t r pply f t n f th fibe g e mıscl A q e of 15–150 imp l pe c d sl w a on es f w g tl d t n d t act o Th magn t d f th gradu l t t d p ds p th f equ ncy f the mp ls s g a th l w a Comb n t f f ta d l we tat n g t g n th rv sy tem d t rm m em nt

which may range a m th gra l pp r jumping mu cl fr m a qu ck powerf il twitch pr p lling th in ect int th a r t sl w walk ng and the t a lv t n n ne e ary to mainta n the tanding p t e

Repeated t mulat n f tl e fa t y tem a i es a co tinuou horten ng (tetan) that de el p h gher ten i ns than tl e r ached dur ng a ingl t itch Indı idual tw tcl es f int a tet nu at stim l fr q e cies ranging fr m less than 20 to a much as 0 p r ec nd S ngle twitcl may oc cupy fr m 0 0 ec to er l ec nd In s u f th h gh v all mu l ten (20 kg g f muscle in the l c t jump ng mu cl) the maxim m ten de el p d in the indi idual i il ul r muscle fil f n e t a e about the s me a th e n co ntered n frog mu l fiber Tl e w rk perf rm ance in the tw gr ups is al e mparal l See MUSCLE MUSCLE (BIOPHY ICS)

Flight Wing ha l appe red n some insect gr ups by the D nia It i th ught that th y s rved fir t a mm able glid ng urfaces I m t mod rn in e t the w ng are hinged t th meso- a d m tath r x n s ch a way that ela ti d l rm ti of th t l deflect the w ng thr gl a path ghly di g nal to th l ng axi of the body Prim t d nymphal in ts fa k wi g alth ugh m t ad lt f rm i ll th major der (exc pt fl es) ha e tw p ir

The flapp ng m t n f the wi wh cl pro- v des m t f th power for fl ght i c u ed l y co tr ct o f the ind t fl ght m le I the l igher e t these mu les c n t tally f tw fiber g p unning t ght a gle to ach th a d atta hed t the la t c ut cular plates en lo ng th th r x The th r ic def rmati p od ed l the l ng tudınal h rı ontal musel reve ed l y nt ct n of the ert al m l and these mus- les tra t alter ately d n g ing m me t The d ect flight m cl s r ng fr m mod fied tu bul leg mu cl in l w flapping pr m ti in ect l k gr h ppers a d drag nfl es i fil r ll mus- l fill g m t f th th ax in high r in ec F b lla mu les a e m de p of large f l e up t 1 8 mm n d am ter They re fi c lored y ll w r p k f m h gh c n e tr t n of re pirat y en zyr s These fiber l e l tge b dl f fibr ls nd c ntain many i gularly placed elei d g at n mbe s f large m toch nd a or reo- mes The l tter a e th e t f the e zyms u d met bol m

S p r mp ed n the flapp g m t n f th w ngs cha g n w ng ngl t the t p a d bott m f a h w g t oke The e a g il r changes re e s t al ht i i g a r lt nt f ce of l lt nd f r wa d th u t fr m the flapp ng m ti n The wi g m em nt an b l kened to a hel c pter w th o l l r t d f r tat ng bl de Changes in w ng angl b ght bo t n pa t by the compl wing i il t n t th th a nd n part by the pull f m ll mus l s att ched d ectly at th w ng ba Th d ect flight m cle nabl many ect t h er fly b kw d and make t ght tu by et g d ffe nt ally on th wi gs

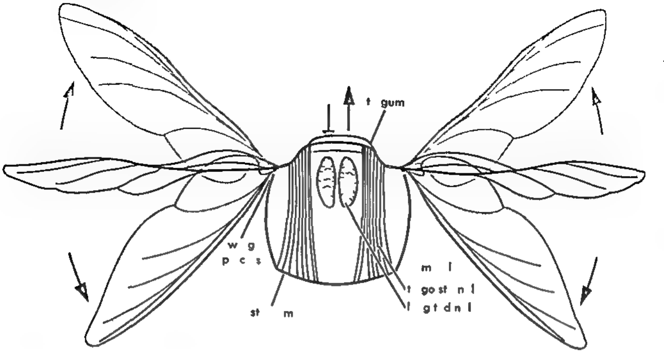


Fig 6 W g movements m the fl ght of an i sect (From T I Storer a d R L Usi ger General Zoology 3d ed M G aw H ll 1957)

In in ects with two pairs of wings the hindwings flap in air rendered turbulent by movement of the forewings and their aerodynamic eff ciency is thereby impaired In the butterflies moths bees and wasps the hindwings have become reduced in size while in the flies they are lost They may be coupled by hooks to the forewings so as to produce the effect of a single moving air foil In beetles the forewings (elytra) serve only as covers for the hind wings which provide the power for flight

A unique characteristic of insect flight is the high frequency at which the wings may beat This ranges from 5 beats per second in large butterflies to as high as 1000 per second in small midges Most gras hoppers dragonflies and moths have wingbeat frequencies of 15–50 medium sized flies 100–200 bees 200 300 and mosquitoes 400–500 per second Since the indirect flight mu cles con tract and relax once during each beat the higher frequencies imply an unusual muscular perform ance

With a few exceptions insects beating their wings le s than 50 times per second have flight muscles similar in structure and physiology to the tubular mu cle found in the legs and other appendages In the e each motor nerve impulse from the nervou system brings about one muscle contraction and one ensuing wingbeat High frequency wingbeat is a sociated with fibrillar mu cle One physiological pe culiarity of this mu cle i that it contracts a dozen or more times for each motor nerve impul e The e impul es appear to generate a critical tensi n at which the mu cle become un tal le a cillate and does work In other word the rhythm of fibrillar mu cle is myogenic and independent of mot r nerve impul e frequency This o cillatory property of fi l rillar mu cle is not fully understood l ut it de pends upon a critical ten ion generated l y n rve impulses in addition to critical inertia and damp ing of the load the elastic properties of the thorax and in some cases a mechanical click mechani m in series with the muscle and its load When the muscle tension surpasses that of the spring in the click the latter goes abruptly from the up m the down position and the muscle goes suddenly slack This slackening may destroy the mu cle s ability to develop tension thus permitting the click to return to its original position It is not entirely clear how this facilitates the oscillatory behavior of fibrillar muscle A click seems to be in olved in the flight mechanism of some flies and in the ound producing system of cicadas In the latter a stiff convex membrane (tymbal) is vibrated in and out 100–500 times per second by a fibrillar mu cle attached to its inner surface

The air speeds of insects rarely exceed 15–20 mph although some dragonflies may reach peed of about 50 mph for short periods A tethered fruit fly is capable of 2 hours continuous flight and 1 500 000 wingbeats l efore exhaustion Tethered lo custs are capable of 5–8 hours of unbroken flight Little is known about the di tances free flying in sects can tra el nonstop Fa rable winds are un doubtedly resp n ible for reported trips of se eral hundred miles

The immediate energy source for short fligl t is sugar An exl austed fruitfly is capal le of f irther flight within 30 sec of feeding on sugar solution Fat re erve are drawn i p n during the longer flights of locu ts Bees may f rage e eral miles for nectar which c ntain i p t 0 sugar Long trips are uneconomic howe er in e m t f tl sugar is u ed in fueling tl e r turn flight

The energy expenditure duri g fligl t r acl e 2000 kcal/kg of mu cle p r h ur 10 tim tl at f human heart mu cle an l twic tl t alculat d f r

humm ngb rd fli ht Sugar i oxidiz d with n and r t flight muscle by enzyme e nta ed in the nu mer s mitoch nd ia The xyg n on umption dur i g fl ght m y b 50 t mes th t when at rest and the temperatu e n the th rax may ri e 10–15C above the esti g temp atur

Fl ght can be in tiated in mo t insects by l s of co ta t betw en the feet d th gr und Light i t n ty flicker odo s and the relati e w nd pa s ng er th e t body all play a part n ma n ta ni g nd stee ng fl ght acti ity Stab l zation of p t h d yaw t nd nc du ing fl ght s s i ted by inert al r gy o pi torques cting o the mov able he d of d ag nfl es the h lte es of fl es and p bly o otl e ppendag s *See* Flight

NERVOUS SYSTEM

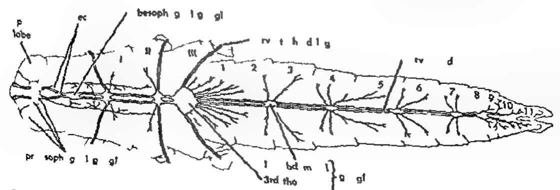
Th s ateg ry nclud s the n rve mechan sm of *tran m on a d integ ati n* ly ng between the s n rga s and the mu l s or gland Th nerv ou ystem ca not p pe ly be con idered apart f m th i p t and tput y tems s n e they pro ide th pathways int it fr m the uter world and the m whe by t act ty exh l ted a be li i H w r the nerv u y t m does m h m r tha me ely c ect ens o gans nd mus cl Th s illu t ated by *what may b called its* pe m e p p rty Throughout l fe the n sv y tem s bomb ded by c nt u but fluctu ti g b rr ge f en o y nerv impul e f om ma n g s y t nly a mall pa t f tl put be le rly trac d t utp t n the form f beha i r l respo S mil l th nerv s y t m s co nected w th all k l t l m les y t *ys po e be* ha al e p n e m d p of h gl ly e tr ted p tt n and seq n e f m le ontra t Th the perm ive q l ty f the ervo sy t m c b l k n d t r hip r l m tat on f th p ad of rv ex tat to p fi p thwa

In ert r well s ted for tud of l h and th bl m Th r b ha io th gh e mplex f qu tly f ll w t eotyped a d i born patte n M t of th *rvo sy tem lik that* of the in rteb at p ead out n a h i of ga gl a ly g l t th e tr l d f the b dy O l the bra n is dor al ly ng in the l ead in close c ntact w th the eyes and antennae Ea h pair of ventral gangl a i a emia ton mon center f r the n e organs and mu cle f it body s gment Long tudi nal conne t e j in gangl a and l rain to provide pathway for the integrati n of their separate ac tivities into a unified pattern of behavior

Th ee general approaches l a e pro ided inf rma ti n on the phy ology of the nerv us sy tem Th surgi al approach or ablati n draws conclus on f om the change in beha ior that f ll w the cutting of nerv r the r m val of part or all of specif c gangli The electrophy l g cal appr ach aims to i olate and i map *in detail specific e nts in n ural t an mi n a d integration* Th method dep nds up n prect stim lat on of nerves and upon detect n of the lectrical sign of nerve ac ti ty The b havi ral *appro ch lea e the animal* i tact and ob rves its react ons t mea ured en i ronm ntal changes *See* Nervous syste i (inver tebrate)

Ablation Th urg cal *appr ach g es back to* the anc ent Greek who n ted the abil ty of a head less in e t to p *rform many c mp lex acts It h s re* ealed th following facts about the in e t nervous sy tem A s ngle i lat d body egm nt bear ng a pair of l gs is capable of a ariety of respo Th se i lud gra p ng by the feet when they en *ount an obje t w tl drawal of the l g from a* xi us i mulus *alternat rhythm c leg move* ments a in walk g and re piratory m vem nt Some of thes act itie are mo inten e after neu al is lat n f segme t others are less so *Oth p po e a t* that may l e c ntin ou in isolated s gm nt or groups of segm nt are c pu latory mo m nts in the pray ng m nt egg lay ng in a n mber of in ect nd th sting ng mo ement of bees

In the intact in ect thes a ti i e tak their pr pe s quence in the total p tte n of beha ior th ough the a t on of exc tat ry and inhibit ry rvou i flu nces r hi g the local g nglia f m the bra n nd oth r ner e c nt rs Th s leg and f ot mo ement a e coo d nated in the six legs o a t p od c fl ti locomot by en ry nd



Fg 7 G h pp rv y t m d l w (F m T l St d R L U g G l Z l gy 3d ed M w-H ll 1957)

nervous interactions of the three pairs of thoracic ganglia The brain in addition to serving as a receiving and coordinating center for the input from eyes and antennae determines the pre ence and direction of locomotion by a combination of excitatory and inhibitory neural actions on the thoracic centers The local activities of copulation egg laying and stinging are suppressed most of the time by higher nerve centers and only released and steered by them under appropriate stimulus situations The mechanisms of posture and stance due to a steady contraction of certain muscle groups have much the same origin in semi independent local nerve mechanisms subject to coordination and regulation from higher centers

Electrophysiology The electrophysiological approach depends to a greater extent upon a knowledge of the finer internal structure of the nervous system this is information that is much needed concerning insects Sense cells just below the cuticle send nerve fibers (axons) into their segmental ganglia Axons from motor nerve cells within the ganglia leave the nerve cord to terminate in muscles and glands Internuncial nerve cells within the ganglia connect ensory and motor nerve fibers in a dense central region known as the neuropile Points where sensory fibers influence the activity of internuncials and the latter in turn influence motor nerve fibers are known a synap es

Nerve impul e tran mi ion along in ect axons is basically the same proce a in other animals Each impulse appears to be a digital event with a high safety factor Special giant fiber ystem with axons as much as 40 μ in diameter (large t mammalian axons are 20 μ in diameter) are concerned in rapid respon es such as e cape from predators although most insect nerve cells are about the same size as in larger animals It follows from this that the total number of nerve cells in the in ect nervous system is considerably le s than in vertebrates and even large muscles such a the jumping muscle of the grasshopper are supplied with only two or three motor axons

As in all animals synap e are important as limiting mechani m in the nervous ystem becau e of the greater in tability of impul e tran mi sion from one nerve cell to another as compared with impulse tran mi ion along an axon Synaptic tran mi ion is readily modified in vari u way by previous activity and by changes in the chemical envir nment of the nerve cells concerned An imp l e arri ing at a synapse may excite or inhibit the recipient nerve cell or it may modify previou acti ity or influence the re pon e to impul e arri ing o er parallel synap e For the e and other rea n ynap e undoubtedly play a maj r part in the permi i e properties of the nervou ystem

There is trong evidence that recipient nerve cells are acted upon by chemical ub tances or mediator relea ed at the ynap formed by impinging nerve fiber Acetylcholine identified at ynap e in other animal appear t be the media t r at me in ect synap e Nic tine is toxic to in ... of its acetylcholinelike action

on their synap es A large do e of nicotine acting generally on a number of synapse erve to up et the permissive properties of the nervous ystem and cau es general mu cle pa m An important group of modern insecticides the organopho phorus compounds inactivate an enzyme in nerve tis ue whose normal role is to destroy acetylcholine as oon as it action at the synap e is completed Per i tent acetylcholine at the synap es cau es di coordination and spa ms

Transmission of nerve impul es along axons and at synapses can be detected as electrical changes These electrical changes are due to rapid ma s movements of ions particularly odium and pota sium along diffusion gradients acro nerve cell membranes It follows from this that critical concentrations of the e ions in the fluid urrounding nerve tissues are of ome importance Since the concentrations of the e ions in the blood may fluctuate with diet the ganglia and nerves of in ects are separated from the general circulation by a pecial heath that appears to regulate the penetration of alts and other substance into the nervou ystem

Behavior It is impo sible to make many generalizations about in ect behavior ince the acti ities of in ect are a varied as their body form The most that can be done is to point out a few fact of in ect biology that provide clue to the kind of behavior likely to be encountered

Insects living in temperate climate are e entially seasonal in their activitie The egg of a pecies are all laid at the ame time of year and one to several generations in which all the individual of a population are at ab ut the ame de elopmental stage are completed in the cour e of a ea on This means that in mo t in ect there i little or no contact or interaction between immature tages and adult and that each stage with it own specialized way of life may last for only a few day or week

Thus the nature of mo t in ect life cycle lea es neither time nor opportunity for behavior pattern to be acquired through emulation of experienced individuals Thi mean that mo t of the highly complex beha ior pattern a ociated with orientati n f raging feeding and reproducti n are a innate and ine itable a i the unf lding of body form which appears complete in all detail as soon a there is coin iden e of the appr priate developmental tage and the re lea ing timulu ituati n The adapti e perf ti n and beauty of the elab rate eq ence of action made by f raging wa p and bee tempt speculation bout f re ight and intelligence but there is no e iden e that the e actions are determ ned or g ided in any way ther than that een in the dev l pment of a p ttern of colored cal on a butterfly wing

Th inevitability of m t in e t beha ior d es not mean that in e t an t learn In fact learning and memory of a high rder ar part of many be... r pattern in b e a d wa p

In many artif ci lly d igned ma e in ect learn sl wly a d sh w p or r t nti n H wever s litary wa p ha e a triking apa ... l arn th

raphy a d landma k of the for g ng ter it ry b ing able to reor ent th m el es immed ately when tran p rted t noth r pa t of t in a darken d box A w ker honeyb e ret rn g to the h e fr m a rich ource of nectar not only emember and is able to r tra e t path but i bl to commun cate by me n of a d n e the d tance and di ect n f the food so ce t the wo ke s within th d k ned h A th r learn g proce s f m inter e t i p im g n i nd t on ng In many in e t the ite cho en f r gg lay ng highly pec fic This may b a sp i l food pla t r m pa f rm a part l r h t pe e Wh n tl t me l ght lat t d in th choi e th female may be in fl en ed by the odor of th particula food up n wh h h w s nou hed a larva

E amples f in e t ntat on h ve be n gi n in th e t f th t cle on en e organ O ent t mech ms rang f m s mpl turning toward away from a stimul (uch a n hem l t sp l ght, or oth infl n) to the comple l ght compa o i nt t n ed b b e arts and w p n th e t ag g e p d ti n The n ts na gat w th m pre i i n over l g d tan by m ng at a fi ed a gl to th un r ts p la zat patt rn For interval f m e th n a few m nut b tween for g g tr ps this type of igati n bj ct t an err r d t dis pla m nt f th un from t t west H wev r th e nd ma y oth in e ts appear t ha e a bu lt t me en that p rm ts them to e npen t f nd pl eme t Th tim en e i m n fest in othe way B fed h f ecta l tw en 9 nd 10 m w ll eappea p mptly at the am p t 24 h urs lat en when the ual sola c a e la king If b tw n th fi t a d e d feed g the h mo ed t n nti ly tr ng a ea the bee t ll t k th rigi al com pa b g i m the hi nd e rch at the co re t d tanc at the p op tim f day

A tim al man f t th daily acti ty hythm f nd n m t ects F in ta e ock oa h s m about h f food at n ght and g th a tiv gr up du ng th d y H sol h g h lte at n of l ght a d da k e el m ted th 24-h r t tiv ey l p rsi ts f me time S mila d l rhythm of e gr at fi ty fo d n m ny the a m l

Mo t n ts le d a sol tary l f a d ther littl nt r t on betwe n nd duals f spe es x pt fo m t ng I rm s f m the m le l kely t be tt ked a d e t t th t me al th gh p c al l me han m elab te c u tsh p beha i may ea e the han es f f rt l t b fo e th male i med Th oci l ect u h te m t s ants bee and w t p e nt th th r e t m of this tuatio In them th o l h l t i blig t y th wh l col ny be g d i ed f m nd d pendent po the re p od ng di id l r qu n hestm t re gn t nd l ny oh r ce e det rm ed b an od r c mm t all m mb and un q to th l ny Th ub q ty f th od d m ned ap p tly by th food t k f th ol ny s a ed by f qu nt act of food regurg tat n and exchange betw n i d vid l Intruder from an th r c l ny are immed ately attacked alth ugh para ites within th n t may b able to ac ju re th od r and th go unm lest d See SOCIAL I ECT [K D R]

B bl graphy K von Fri h *B es Their l is on Ch mical Sens s and Language* 19 0 G Hoyle *Comparative Physiology of the Nerv us Contr l of Muscula Contracti n* 1957 J W l ringle *Ins ct Fl ght* Cambridg Mon graph in Exptl B 1 9 1957 K D Roeder (ed) *Insect Phys ology* 19 3 V B Wigglesw rth *The Prin iples of Insect Physi logy* re ed 1953

Insecta

A clas of th phylum Arthr pod som t me called the Hexapoda Th s i the largest cl f animal contain ng about 1 000 000 d cribed pecies l n the e ar po sibly a m ny a 10 000 000 act al spec es of n e ts Like oth r arthropod th y l a an exter al ch t us co ering Th e b dy i d ided into serie of rings or gme t wh ch d ff r fr m th e f all other arthropod since the g ments a e u ually arra ged in three di tin t g r s I ct ne e po m e th an three pairs of leg a d m t pecie ha e w g The integ ment i compo ed ba ally of a comple l t nce alled l t n wh ch may conta n ther s l t nce th at giv it e lo and stiffn The e ther s b tances of a p ote eo nat re are g nerally d po ted in d s tinct ea e lled sclerites Scler tized are are d m rcated f m other s m lar a e by memb a nou *lin s r fer l to s it r* S ARTHROPODA

The cla ificat on of in cts is ba ed n th p im ti v presen e o ab enc of wing F rm wh h re

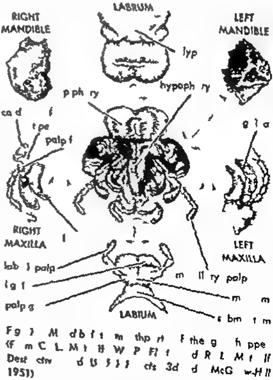


Fig 1 M d b l s m thp rt f the g h ppe (F m C L M t B W P Fl t d R L M t If Dest ctiv d U S l l cts 3d d McG w-H ll 1951)

tain the primitive condition of winglessness are placed in the subclass Apterygota which evidently descended from winged ancestors in the subclass Pterygota There is a difference of opinion as to the number of orders of Insecta Some authorities recognize as many as 36 others less 30 would be a conservative estimate Each of the items classified in the outline will be found as a separate article

Cl Insecta
- Sub l Apte yg ta
  - O d P otura
    - C ll mbol
    - Diplu
    - Thysanura
- Subcl s Pt ygot
  - D vis on H m m t bola
    - O der Orth pt
      - Dermapte a
      - Plecoptera
      - Isoptera
      - Emb opt
      - Od n ta
      - An sopt
      - Zyg pt
      - Ephem pt
      - Mall ph g
      - Anoplu
      - Psoc pt
      - Z pt
      - Hem pt
      - H m pt
      - Thy n pt
  - D *on H l m tabola*
    - O der M copte
      - N opte a
      - Lep d pt
      - D pte
      - S ph n pt r
      - C leopt
      - Hym n pt

ANATOMY

The head thorax and abdomen are the three main divi ions of the insect body

Head The head bears the mouth and associated appendages as well the antennae and eyes The mouthparts are composed of four closely united tructures the labrum (upper lip) the mandibles the maxillae and the labium (lower lip) The mandibles are heavily sclerotized structures which crush the food The labrum co ers the mouth opening while the maxillae manipulate the food and the labium covers the under surface of the mouth Within the buccal cavity or cibarium is a tongue like structure the hypopharynx Basically the e mouthparts are modified for chewing however there are various departures from this type among insects

Various glands discharge their contents into the cibarium The most important are the salivary glands lying in the thorax and opening internally through a common duct at *the base of the labium* These structures which produce the salivary secretion are of great importance in those species serving as vectors of di ea e producing organisms The best known product of these structures is the silk of the silkworm

Antennae The antennae which u ually consist of several segments are very slender organs attached to the head in front of and between the eyes They are present in all but a few insects even though sometimes reduced to vestiges of a single egment. They are the principal organs of mell but in some insects they have an auditory function and probably have in all insects a tactile function

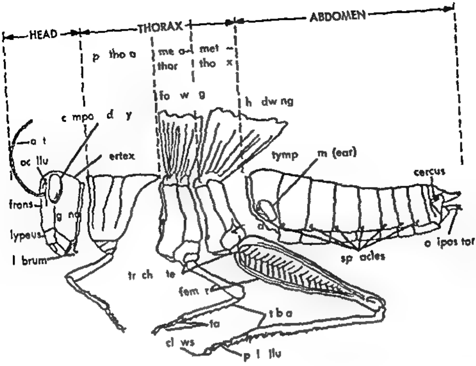
Eyes Two kinds of eyes occur compound and simple The compound eyes are commonly large in some insects they compri e the greater part of the head but in others may be small or lacking They are composed of from 1 to an estimated 28 000 facets of clear epidermis each with a light sen itive structure beneath it Each of the simple eyes, known as ocelli or stemmata has a single facet overlying the light organ There may be everal of these in some insect larvae but adult in ects never have more than three

Thorax Usually connected to the head by a di tinct membranous neck the thorax is compo ed of three segments that are quite closely united but generally recognizable The first of the e the prothorax is commonly the most distinct and bears one pair of legs The second and third called re pectively the mesothorax and the metathorax each bear two legs and two wings Generally these egments are quite closely united to form a sort of box which carries the mu cles for the legs and for the wings The wings are always undeveloped in immature forms and the legs commonly so

Legs The legs are divided into six sections or segments The basal segment or subcoxa is flattened and expanded It forms the side walls of the corresponding segment of the thorax The second segment the coxa forms at times almost a true ball and socket joint with the subcoxa thus permitting movement in any direction The third segment, called the trochanter is very small and quite often is divided into two parts The fourth segment the femur is invariably the largest and longest The fifth the tibia is shorter The tarsus the next segment is commonly di ided into five or less smaller parts with the terminal one commonly bearing a pair of claws All the parts are actuated by a common muscle The legs are modified in many ways for swimming digging running crawling leaping or clinging to the hairs of other animals Although some parts may be absent legs are always formed upon the basic pattern described

Wings In many respects wings are the mo t important structures of the adult insect body (except for mayflies immature in ects do not have wings) The way in which wings develop is one of the bases for broad in ect classification into orders familie and even smaller groups So precisely are they associated with particular groups that an insect can *frequently be recognized on the basis of a single* detached wing Knowledge of fossil in ects depends largely upon the wing because they are among the more readily fo ilized parts f the in ect body

Wings may be likened to cellophane sacks that are pre ed flat at maturity and which ha e wires in the opposing surfaces t stiffen their structure All cellular structure und rlying tl e surfaces has



Fg 2 Outl f b dy f g asshopp I t I w D st ct d U f I I ct 3d d M G w-H ll ll m C L M t lf W P Fl t d R L M t lf 1951)

b e l m t d W g b g n t f rm ı the ımm t r ın ect f om a gr g f ll en lo d by th ck a d t ı th body w ll Th s ck (t elf a ll t t) app n th s bles rfa e i the body th o- ll d E pteryg t th E d p- teryg t th a k s l d b th the de m u t l a ta st g n d lopm t ched W th the k th ell m lt ply thro ghout g th of the sect They e t ely ns med n the p d t f th wall d th ta n d bl d ı withdr wn t the fi al m lt wh th walls fl t t o tt f rm th p f t w g

Th w es th wall f th wı g the reu e s r fa d d wn n gl b s patt rn h h mm t ll n t th ugh p ble of ı fi t t det l M h f the l s fi t n f ı se ts depe d on th a tıo and k wledg f th m n t t tes a m) r equ reme t f r ect t x m t.

Abdomen Th th rd ct of the t body th bd m ts b lly of ll gme ts Al th gh th mb ft ed ed p ally at th p t r d f th body t ne r ed Th app d g leg f thes gment a e p s- t ly t ges the embry s pt n the t mı l gm t wh th a e c n ted t t l the ır t s that d the ge p n g both the m l d f mal d a m h mpl ed by p ese t d y e t m l g st t d t g h n p f ects

A g t l t u t the f m les the o ıp t egg pl c g pp at Ge t l ary de bly f rm d m y be l ck g ı me gr up Th y re mod fied a the stı g among the bee and wa p and ın ert ın para ıtıc relat es f b es and wa ps may f rm an rg n l nger th n the body fo dr lling ınto wood In some r lat e f g a h ppers gen talia tak th f rm of bladel ke tr ct res as lo g a the body

In the mal th e truct res a e modifi d ın many strange w ys to fo m orga s f r gra p g the body of th fem le a d for penetratı the l a These org m y be the t ly exp d or re- t a ted ınt the b dy f the male except when ın u e

Respiratory structures All ı ects e cept pos- ıbly a f w of th ery mplest f rms br the th gh a ystem f tube which a e ı ag nat f th derm d wh ch mıfy thr ghout the en b dy Th tubes a e c lled trache e d their p gs t th e ter or called sp acl The t bes end ın mı ute t h l which penetrate mong o nto the d d al ells of the body t u There a e ne r m e th 10 pa rs of pı r les ı any ı ect A p b rne o ea h f the fi t 8 gm t f the abd me and I ea h th m thor x a d metatho a Th s numb r ıs re- d ced to as few as pairs on the thorax ı me spec es I many aqu t c f rm th spiracl s a e r pl ed by gill whı h m y ccu on alm t ny p of the body The m m t f g s s th ough the t a he l system ıs e t lled ther by body mo eme ts f mp g n t re by d ff on f th ga th ough th cles or g lls Th final t a sfe withı ll body th funct n of the tra cheole

INTERNAL ANATOMY

The internal structure of insects may be considered in its five major aspects: digestive, excretory, circulatory, nervous, and reproductive systems.

Digestive system Insects possess an alimentary canal extending from the mouth at the anterior to the anus at the posterior end of the body. This canal varies in form from straight to convoluted. It begins with the buccal cavity or cibarium, continues through the pharynx, which serves as a gateway and sometimes as a pump for liquids, and on through the slender esophagus, which may expand into the crop. The crop, in many forms, is lined with teeth for further grinding of food. Next in order is the proventriculus, followed by the cardiac valve leading into the midintestine, where the principal processes of digestion take place. The openings of the excretory system are at the posterior end of the midgut. The canal narrows to form the short intestine and then widens again to form the rectum. The anal opening, morphologically, is on the eleventh segment of the abdomen.

Excretory system The excretory system consists of from 2 to as many as 150 tubules, called the Malpighian tubules. They generally discharge into the posterior end of the midgut or into the beginning of the small intestine. In some instances they are much folded and thus longer than the body itself.

Circulatory system The blood-propelling organ, or heart, is a single blood vessel called the dorsal tube that extends almost the length of the body. Blood is taken in through openings, or ostia, in the posterior region of the heart, is propelled forward, and then discharged at the anterior end, after which it flows freely through sinuses of the body cavity, finally to return to the dorsal tube.

Nervous system The nervous system consists of a pair of nerve cords, usually closely united as a single cord and extending along the ventral side of the body cavity. In these cords are swellings called ganglia. Typically there is a pair to each body segment, but this number may be reduced by the fusion of ganglia. The two cords separate in the head to pass around the alimentary canal, thus forming the esophageal commissure. They unite again in the supraesophageal ganglion, or brain, which is formed from the fusion of ganglia of all the segments of the head. From each ganglion of the chain nerves extend to each corresponding segment of the body, and also extend from the brain to parts of the alimentary canal. There are several minor ganglia connected directly with the brain.

Reproductive system In the female the reproductive system consists primarily of a pair of ovaries, each with a number of tubes called ovarioles. The ovarioles from each ovary unite into a common tube, and the two tubes fuse to form the oviduct. This discharges through an external opening, the vulva, located on the ventral side of the eighth segment. There are special glands and other chambers that open into the oviduct. The germ cell forms at the inner end of each ovariole and passes through a series of chambers, receiving its supply of food material as it proceeds. In the last chamber it receives its chorion, or shell, which has a minute opening, the micropyle. As the completed egg proceeds into the oviduct, it passes the opening of a chamber, the spermatheca, where sperm previously received from the male is released to enter the egg and cause fertilization. The other glands may at this point contribute various substances used for attaching the egg to a substrate or for covering it.

In the male there are paired testes in which the sperm are formed. From these a pair of slender ducts, called the vasa deferentia, unite into a common ejaculatory duct, and this extends into a variously sclerotized penis. The sperm is commonly stored in swellings of the vasa deferentia to await copulation. Connected with these structures are various accessory glands.

Among the many groups of insects various modifications exist in these basic structures and in their

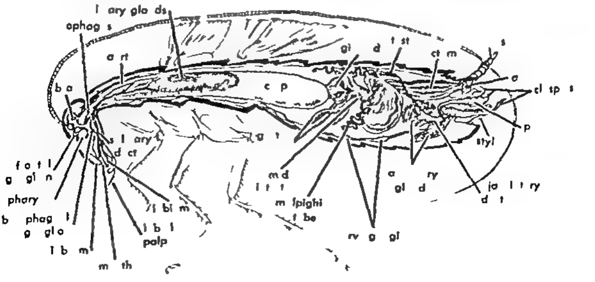


Fig. 3 Sagittal section of a cockroach showing its internal anatomy. (From C. L. Metcalf, W. P. Flint, and R. L. Metcalf, Destructive and Useful Insects, 3d ed., McGraw-Hill, 1951.)

thod of per ti n In f ct almost ery method of eprod cti n that s kn w in th an m l ki g d m c be f und am ng the i ects Cop lati n n rmally cc rs thr gh th vul I t n the bed b g fam ly C mi ida f the rde Hem ptera it t kes pla e by m an f a pec al tructure occur g t a us g nts on the f male body The p rm i ece d thi tru tur d th n p s ed th ough the body a ty to fe tilize th egg n the a le I me in ect the rm mu t pass thr gh th ducts t the o ar le to fert l e th egg b f t enter th id t The f rtil zed m mat r gg d I p t matu ity in the ova i le In some f rm th le r n t tul ular but a e h ped l k b n h f grapes In a few nse t the mbry r t ed with the b dy unt l it i fully g own, ng n u h d by gla dular ecret ns Th r e som th g f pl c tal de elopment some f m f ct

METAMORPHOSIS

After b g hat he l r born n t t only r ze b t they hang in f rm to some de gr i th m j rity to an xtra rd ary e te t The e n i e m r ly gr wth Th h nge i f rm i l es the mo e el b r te pr c es c ll d m t m ph I t ha b n gr uped or las fied o the b sis f the type f metam rph s s th y und utl n d b l w

1 Am t bol p m t n d t n t e t nal h n e e d t with n n re e n ze Met bol u d t nct chang s both in s e a d f m a e d nt
 P u m t bol d ct m tam ph that mpl a d gr d l imm tu f rm e mbl th ad lt e ept n and r re f d t ymph
 b H m m t b lou m tam pho nc m pl t g ll ar nt n quat c larv e, a d
 H l m t bolo mplet or ind ect m t m ph s s t n th s d elopm nt are th gg l rr pupa nd ad lt m g

T a i i tl n t mu t l ak th gh the lat ly nela t d rm l o g Th is d w th the d f rta n h rm n as f ll w A w k n t i g y h g l d d w d rn th th ld Wh n th ew k n ompl t th ld pt r d th t t kes water i th al m nt y l n n and p l ut Th s molt ng erdy The new k at fir t wr nkled d l lded ema n ft and fl x bl l g ough t ll w th b dy t xp d t t fullest t t bef e h rden g ga n By h ed f th dy s, th fi l f rm

Ch g f n s e d nt ly at time f m lt g l t l lee p p d nt r lly b f ch m lt In th f th r us m lt ll the h ng f m the l h t h d mbry t the f ll f med ad lt n t ke pl In som f rm th d lt d ff fr m th ymph l t ge nly n ha ing w ng and e ternal genital In the a t ma jo ity h wever the metamorphosi i mplete and the ad lt f rm n no way re mbl le the imm at ire r larval form The immatur stag and the adults h e d erged far from each th r that tl e tran t on betwe n them i crowded into a ngle t g Externally it appears a a qui t period l ut in t rnally it i a time f inten act ity di ring which th ent re tructure i rem lded Thi per od i known a th pupal tag The larva and tl e a l ilt r imag d ffer n t nly in their tri cture but al o in th ir hab ts whi h usually ha e n th ng at all n c mmon S INSECT PHYSIOLOGY IN ECTA FOS SILS [ ]

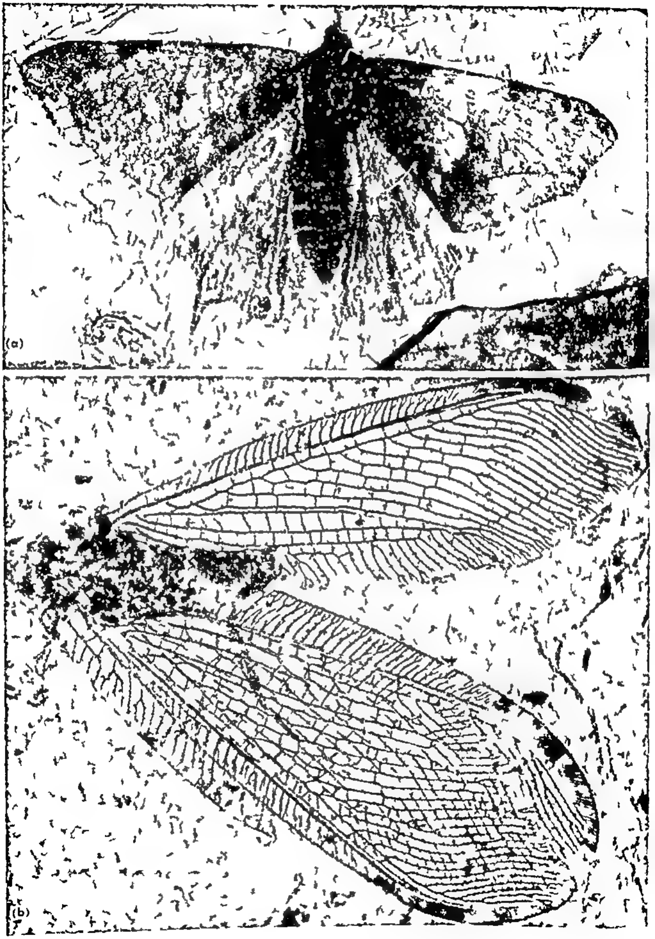
B bliography C T Br e A L. Melande an l F M Carpe t r *Cl s ific ti of I s cts* 2d ed M um Comp Zool B ll 108 19 4 J H Com t ck *I t odu ti n to Ent mol gy* 9th ed rev 1940 E O F g C ll g *Entom logy* 1949 A D Imm *Gen al T xtbook of Entomology* re e l 1957 H H Ro *A Textbook of Entomology* 2d ed 1956

Insecta fossils

F s il i ects ar th rema n or trace f in ts pr erved in rock They t i lly c n i t in part of an impres i n in th ro k matrix and in part f ome altered rgan c sub tan es m re r rely a in the a f i t pr erved in amber m ga comp und s l h t n may p r i t w th ut h ng l g ne al insect bee me pre erved a fo ils by the l urs l of l ving or fre l ly kill d p m n olt m d wh ch acc m l tes ap dly nough t prevent d s nt gr t on of the in s t Th nt al ha de ng of the m id f rms a edim nt ry rock c nt ning th in ect remai The f s l *in ects are obtai ed* by plitting the r k alon pl ne f depo ti n with a h mmer and ch el See AMBER

Fossil record F ssil in cts ha e b en found in b ut 100 d ffe ent r ck f mat n thr ghout th w rld O e f th best kn wn d pos t s a h le bed n the t wn f Flo ant Col ad In the Ter tiary Period of th e th s h tory bout 50 000 000 ye go th w th it f a h llow lak su und d by a t e volca o A the l fr m th l an es f ll nto the wate of the lake t car ed l ng with it whate n e ts were flying o the l ke and the a h ttled on th bottom to fo m mud the n ects w p omptly bu ed The Flo a t hal has y ld d fully 100 000 p ci me f n t (F g l d 2)

Pal o c Th e l e t kn wn f il n cts ab ut 250 000 000 y a ld re fo nd n r ks of Uppe C rb f u (Penn yl a a) age M t f th ea ly i s cts h d pp x mately th si e and ppe e of the li g m sfl es nd drag nfl s to whi h they w l ely el ted A few of th d ag nfl l ke i ts (b lo g ng t o e family f the xti t o d I t don ta) we la ge hav g w ng pr l f 6 in (30 n) Th mo t num o t f th tum at le t i wampy regi w th co kr ches wh ch e mila in ap-



Fg 1 Fo l ect f om M oce e of Col d
(a) P od yas p sepho Sc dde o d Lep d pt

(b) L th myl al mb a (Co k ll) o de Neu op-
t a

pe anc to li ing roa he The early i e ts w re les pecialized than any other known insects and are ually thought to ha been cl e to the an ce t rs of the winged n ects

Th inse t fou d in P rm n rocks (formed ab ut ▇ 000 000 year ▇) represent a far more d ve s fied fauna th n that of any other per od in the rth s hi t ry in luding the p e ent The ex tinct d rs that exi ted in the Carboniferous Pe riod survived int th Permian and n addition ev ral l ing orders were repr sented Along with the hug drag nflylik in ect (Protodonata) w re s ch minute in ects as th bark l e (Psocopt ra) s me ha g wing pread f only 3 2 mm The fos ls how bout an equal repre ent tion of the ext nct o d r of the Carbon f ou and some r latively sp ci l zed livi g ord rs Add ng to this diversity we e e al ext nct o der not found n Ca bon fe ous strata The li i g rders repre ented i th arly Perm ncl de s h types as the dr gonflies (Odon ta) mayfl es (Eph merida) bark l (P ocoptera) H mipt ra (true b gs) and sc rp on fl es (Mecopte a) Th pr e e of the co pi n flie s e peciall i te e ting nce th l v g specie ha a c mpl cat d postembryon c d l pment haracte ist c f all of th most h ghly pecian ed of f ing in ects True b tle (Col p t a) a d stoneflies (Pl pt ra) appe r in Late Perm an d po it

Mesoz c At the beg nning f th Me zoic Era th r o d of f ssil n ct chang s significantly Th contrast between the ar h i fa n of tl Ea ly P rmi a d the elati ly d rn one of the Tr s as gre t s tl t b tw n the faun of the T s c and th R ent (pre ent) *periods* The xt n t pr t d n te dr gonflie pe s ted i t th T s c but appar tly di d ut by the end of that p ri d No e f the oth r xt nct rd ▇ of i cts *i f u d in d p* ts lat th n th P rmia

The i s ts found i Jur s i strata compr e a fau much l ke that f the Tr a *ic ex ept* that m e li ing f m l es ar r pre ent d In general s ch fam l es occur in th n de s that we e well developed the Perm an h as the Odonat d H mipte a Not bly ab t the J ra were fl we i ct in *parti* lar the bee and syrph d flie By th b gi ing of th n xt peri d th Cre t e us th fl w ing pla ts had b ome tab l h d d ll p bab l ty the typ of in cts ssoc at d w th th se plants promptly f llowed Unfo tu at ly nly a *e y f w i t a e k w* f m C et eous rocks

C o i In ts a mo e b nd nt i Te t ry depo t than n ny the *f rm t o s.* The fo ils h w th t a m h high pe entage of li ng ge ra w s p e nt i Eoce nd Olig e tim than n the Jur c Th p es rv d i B lti amb wh h s of a ly Tert ary ag a e e p lly mpo ta t n making p s bl th comp r o s th li g ge e nd pecies Exten i st d f mbe i t h ve sh wn that th m nt f ev l tonary ch ge th t ha t k n pl ce s ce th e rly T rtiary a ie gr atly w th the p rt cula

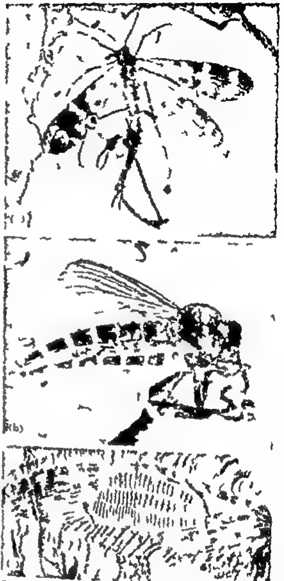


Fig 2 F ssl ct (a) H l o p m l Scudde d Mec pt d (b) bb fly o d D pt f om Mioc e f C l d ( ) Cl l ll and M K w d Orth pte f m T o of N w So th Wal

fam ly of in cts c ncerned For exampl about half f the nt genera fou d in the Baltic amb r (t tab g 43) are l g genera whereas in th ca e f the bees only ngle amber genus is till li ing Se al sp c es of the B lt c ambe ants are ind t gu sh ble from l vi g spec es

Significance Th tudy of fo il i s ts h s m d s gn fi ant ont ibut n to the unde stand g of th ev lut on of in ect and f *the re t onsh p* f exi t ng rd s a d fam l s It h b com ap- ▇ ent that th g o p n w l *ing* are b t a mall pa t f the total numb that ha e e sted on th earth A det led tudy of the f s l forms pr v de den f ert in pr gre i ch ng in t uc ti e a d d velopm nt wh ch n the ma n are on fi med by mo pholog al and d v lopm ntal n s

tigations of living insects There is however no fossil evidence bearing on the question of insect origin the oldest insects known show no transition to other arthropods Morphological and developmental studies however have indicated that the ancestors of the insects were terrestrial arthropods probably related to the Symphyla Although the time of that origin is not directly demonstrated in the rocks the fossil record suggests that it was at least as far back as the Mississippian Period (Lower Carboniferous strata)

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Sodium fluoride has been used to control chewing lice on animals and poultry but its principal application has been for the control of household insects especially roaches It cannot be used on plants because of its extreme phytotoxicity Cryolite has found some utility in the control of the Mexican bean beetle and flea beetles on vegetable crops because of its low water solubility and lack of phytotoxicity

Organic insecticides These began to supplant the arsenicals when DDT [2 2 bis(*p* chlorophenyl) 1 1 1 trichloroethane] became available in 1945 During World War II the insecticidal properties of γ benzenehexachloride (γ 1 2 3 4 5 6 hexachlorocyclohexane or γ BHC) were discovered in England and France The two largest volume insecticides are DDT and γ BHC (125 000 000 lb of DDT was produced in the United States during 1957) Certain insects cannot be controlled with either and there are situations and crops where they cannot be used For these reasons other chlorinated hydrocarbon insecticides have been discovered and marketed successfully These include TDE [2 2 bis (*p*-chlorophenyl) 1 1 dichloroethane] methoxychlor [2,2 bis(*p* methoxyphenyl) 1 1 1 trichloroethane] Dilan [mixture of 1 1 bis (*p* chlorophenyl) 2 nitropropane and 1 1 bis (*p* chlorophenyl) 2 nitrobutane] chlordane (2 3 4 5 6 7 8 8-octachloro-2 3 3a 4 7 7a hexahydro-4 7 methanoindene) heptachlor (1 4 5 6 7 8 8 heptachloro 3a 4 7a tetrahydro 4 7 methanoindene) aldrin (1 2 3 4 10 10 hexachloro-1 4 4a 5 8 8a hexahydro 1 4 *endo exo* 5 8-dimethanonaphthalene) 1 3 4

10 10-hex hl o-6 7 ep xy 1 4 4a,5 6 7 8 8a-octahy dro-1 4-endo xo-5 8-d m thanonaphthalen) en d i (1,2 3 4 10 10-hexa hl o-6 -epoxy 1 4 4a 5 6 7,8 8a-octahyd o-1 4-endo e ? 5 8 d m than naph th l e) toxaphene (camphene plu 67-69% chlo-r ne) and Thiod (6 7,8 10 10-he a hlo o-1,5,5a 6 9 9a h xahydro-6 9 metha o 4 3 b n od oxath e-pi 3-o de) TDE i con iderably le tox than DDT but n g ne l is al m l s effecti e It has g ven ut.ta d ng re ults tl ontr l f larv e f s ral m th ho ve M thoxy hl r i e en le s t i th n TDE d ha fou d con ider ble u e in the co tr l f ho fl s and lso of the Mex can be n beetl h ch i n t u ept bl t DDT Re t ct ns ha e be placed on its u on da ry c ttle fo the ont ol f fli d ts umption i decl ning Dilan has f nds m u e n the cont ol f th M x c n b an beetl a w ll as f s me thrip and aph d Chlo d e wa th fir t yel pentad en i s t c d t h mmer i l tat It h s b th mo t ff ct e hem c l ailabl f r the control f oa he In add tion to l ngthy r du l pr p r t e hlo d ne l po es fumiga t ct n Re-lated h mi l de hepta hlo ald in di ldrin and ndr They a ffe t e a n t gra hoppers and pec lly eful f r th control of insect inhab t g s l To aph e i ed pr p lly f th t l of th c tt boll weevil and othe i ect pest f c tto Th oda i dd t n t sho ing pr mi f r the ntr l of nume us ets als h w p omi f t ll ng numb f pec s of phytoph g (pl nt fe d ng) m tes that are n t gen ally ept bl t hlo inat d hyd ca bon i ect c de

Insect resistance The re i tance of n ects t DDT wa fi t ob erved 1947 n the ho efly B the end f 19 8 2 p f arthropod had been p ed t be e stant t one r m e inse t c des Among th hl r at d hyd arbon s ti ides tw type of es t n occur On appli to DDT a d its an log uch s TDE m th xychl r nd Dil a d the th r t she cy lod en com p d h hl d b pt l lor aldri d eldr n end i d al y BHC nd to phene In t des a n t m t g i d cati g that e tan e p ee t n a sm ll part f the n tural p pul t es b fo e p

Ne ly e y c t y th wo ld ex pt m n l nd Ch na h ported the pr en e of r st t str f th h fly l m n h vily popul ted u b s f the U ted St t t i d ff cult to bt n t ol f a hes w th hl dan During 1957 d 1958 m ny gr wer f ott in the south m st tes h nged f om t xaphe e d y BHC to rgan ph phoru hem cals b ause f th tance f the c tt boll w ev l to chlorin at d hyd oc rbon i secti d The d el pment f t f th n magg t e tant t ld n d d eldr n n the t rn Un t d St tes and in Ont t u g c ern The dev l pm nt of hlo ted h d oca bon r t m ng e ral pec es of d e-tran m tt ng squ t es i a th at i w ld he lth Th e nt l of typhus in the Far Ea t is at stake now that trains of the l ce tran mitti g the d ea e are resi tant to DDT

Organic phosphorus insecticides The de elop ment f th s type of in ect cide parallelled that of the chlorinated hydrocarb ns Since 1947 about 50 000 o ganic pho ph rus c mpound have been syn the ized in academ c and indu tri l laborat r es throughout the w rld for evaluat on as potential in ecticides Parathi n [*O O* diethyl *O* (*p*-nitro-phenyl) pho ph roth oate] and *methyl* parath on [*O O*-dimethyl *O* (*p* nitrophenyl)) pho phorothio-ate] are e t mated t have had a w rld production of 20 000 000 lb dur ng 1958

A g eat di er ity of acti ity i found among r gan ph sphoru in ect cide Ma y are extremely t i to man and th r w rm blooded an mals but a few how a ery l w to ic ty Th more imp r tant include tetraethylpyr ph phate Chl rothion [*O O*-d m thyl *O* (3-chl ro-4-n t ophenyl) ph s-phoroth oate] Malathion [*O O*-d methyl *S* (1,2 d ca beth xyethyl) ph phorodith o te] DDVP [*O O* dimethyl *O* (2,2-d ch l n nyl) pl ph te] D azinon {*O O*-diethyl *O* [2 i op opyl 4-methylpy imidyl (6)] phosph roth oate} Delna [2 3-*p*-di n d th l *S,S* bis(*O O* diethyl ph phorodith o-te)] Coth n [*O O* d methyl *S* (4-o o-3H 1,2 3-benz tr a ne-3-m thyl)) pho phorodithi ate] T i th on [*S* (*p*-chlor phenylthi methyl) *O O*-d ethyl pho ph rod thioate] Ethi n {bi [*S* (d ethoxyph phin thi yl)m r pt]methane} EPN [*O* ethyl *O* (*p*-n tr phenyl)) ph nylpho ph noth onate] and D pt rex [*O O* d methyl (2,2,2 trichl ro-1 hydroxy ethyl) ph ph at]

Schrada [bis(d methyl mi o)ph ph ric n h d de] w s u ique am ng organic in ecti id in th t it how d y temic prope t es whe appl d to plants By di ect c nt t it ha relati ly low rde of acti ity When pr yed on plants, t i b o bed f om areas recei ng treatment tran lo-ted thr gh ut the entir plant and i metabo-liz d t y ld a prod ct highly t xic t s ch suck g p ts aph ds nd pl yt phagous m tes It is electi e in th t it affe t o ly aph ds ngesting ju ces f m t e ted pla ts nd does n t k ll pr d t wh ch d tr y aph d With ch dan it is n w p s ble to p t t the grow g pa ts of plants without e t ng t f qu nt sp aying becau the in ect de is t ansl ated t these gr wing parts wh s with mo t tomach p i on or re d ual n ecti ides pl nts o tgrow th protection Seve l chem cal how ng sy temi pr perties have ow re hed c mme ial n n a commercial tatus Th i cl d Demet n [*O O*-d ethyl *O*(and *S*) (2 ethylth)ethyl phosphoroth oates] Di Sy ton [*O O*-dieth l *S* (2 ethylthio)ethyl phos-pho odith te] Thim t [*O O* diethyl *S* (thylthi omethyl) ph ph od th o te] and Pho dr [2 m thoxy arbo l l m thyl inyl dimethyl ph s-ph te]

Th u f gan ph pl orus chemical f r th y t m c co tr l of an m l pa ites i another f et of i te t D g 19 8 m omme c al p-pl ation of Co-Ral [*O* (3-chlo o-4-*methyl* ylumbellif

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(Talp d e) bse t only from So th Ameri a Aus- tral a, and Mad ga ar See EUTHEPIA MAM MALIA [D D D]

Insectivora fossils

Fo s l i ect ores are referred to two gr up on l ar-cut ah th r les well defined Th fi t gro p i c mpo d of in ecti or s in which the in te tin l cecum is la k ng and the taped al art ry th major sou ce of blood upply to the bra n. These are kn wn a the Lipotyphla or In ect o a pr p r All li ing in ect vor s ex ept the el ph nt sh e (Mac l d d e) nd tr e sh ew (Typa d e) mo t late Cenozoic and a few early C n ic and po bly Cr ta eou insectivores belong to th s fir t group f e t r The econd group is g n ally more primit ve and is pr marily early Cen zoic n kn wn ccurren e Li ng members ha an nt t nal cecum and th blood supply t the bra n t ll p miti ely e mple The stapedial rt ry not a import nt as i the lip typhl ns P imate tupai ds and ma ro celidid a e de- end d f m arly repre ntati es of this eco d gr up ometimes alled the M n typhla.

Lipotyphla I the Lip typhla the ancestry of the hedg h (E i c dae) has been traced b ck t the Oli e Eura with ut que t n nd still m e prim ti e an esto s h ve been t ntatively ide t fi d a ly a th m ddle Eo ne in the U ted St te Cl ely l ted f rms are known as ea ly th e d f Cretaceous t m These forms r clos to the an e tral M notyphla n known t u tu e Th p n pal h m l d of the hedgeho s h s alway been E s a All but the ea liest ec ord f the fam ly in N th Am c r p nt ab r ea t d ri at f th m r ent al E a i n t ck. The f m ly eve r ached South Ame i a r Aus- tr l a both f whi h wer land duri g mo t of the Cenozo c A id bran h, the D myl da flou hed n th m ddl C z of Eu ope (Fig 1)

Th Sol nod t d e nd Ne oph nt dae a e fairly cl sely l ted W t I di n f mil of l rg but ne e th l me h t h wl ke lipotyphla O ly th Nesoph t d e wh s man a e f nd n l t Q nary d po t li e a fo l reco d B th famil ar b l ed t h be ome l ted th West Ind es n th e rliest C zoic M i l nd N rth Am n Ol goc n g r (Apt rno- dus and others) previou ly th ught to have gi en r e to them are now known not to have d ne so

Shrews (Soricidae) have been traced back to the late Eocen (Saturnin a) and prior to that their ance try merges with that of h dgehogs Fo il forms differ l ttle from their m dern counterparts in known tructure except in the exti ct ubfamily Heter oricinae in which the jaw is sh rt and the teeth omewhat more hedgehoglike than in other shrews The fo il record of shrew is primarily in Eur pe and North America

Moles (Talp dae) are known fr m both Europ an and Amer can dep it as early as the beginning of the Ol go ene b t at the r first known appearance the moles were already well diff rentiated De man moles how an appr ach t the hedgehogs howe er Th characteri ti talpid digging humerus is one of the mo t ea ily dentified fo il bone in the con ti ental C no ic rec rd

T nrecs (Tenrecidae) who e Recent representa t es re confined to Madaga car except for the aberrant subfamily Potamog l nae of West Afr ca ha e a poorly known fo l reco d in the early Mio- cene f Ea t Africa Th y are bel eved to be deri a tives of the nce tral Eri aceidae but the details are unknown

Another Af can lineage f probl matical lipo- t phl n is th Chrysochl ridae or golden moles These ha e a Ple tocen record in South Africa and ha e re ently be n found in the arly M ocene of Ea t Afr ca The r affin ties p obably lie w th the ten ecs though in eality l ttle i known of the orig n of the peculiar m l like animals

Menotyphla The ec nd les well defi ed group f ect o es r Menotyphla cont ins the li ing el pha t hrews a d tre shrews of Africa and South a t A These are primatelike (particularly the t ee sh ew) and ar f equ ntly plac d n th Pr mates by work wh reg rd the hedg h gs as mo e primiti The fo l rec rd f elephant h ew goe ba k to the e rly Mi ce of Ea t Af r ca Two s ppo d tupa ds (Anag le and Ana galopsis) h e been fou d n the middle and e rly C no o of Cent al A ia and a middle Paleocene N rth Ame i n f rm (E da m nema) may belong to the T p idea

Six early Cen zo c families are te t ti ely re- ferred to the M otyphla Th L pt ct da (Ictop D acodo and th rs) ranged fr m middl Pale- o n to m ddle Ol goc e n North Ame ica (Fig 2) Th P nt lest dae (Pa t l st s Aphron us a d ther) we la ge q t e f rms known f om th middl P leoce e t th e rly Olig cen i N rth Am r a nd arly Eocene nly in Eur pe The Apatemyida (Ap t mys Het ohyus and oth er) w r pe fic ally rode tlike fo ms that rang d fr m th m ddle P le ce e t e rly Olig cen in N th Am and f om the ea ly Fo ne to th lat Eocen Eu op The M xode tid are an oth p fi ally odentl ke g o p onfi ed to th Paleocene f N rth Ameri a The Zal mbdal t da (Zal mbd lestes only) occur in th Late Cret

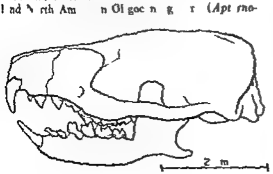

Fig 1 Sk ll d l w j w f Amph h mid C l p typhl sect vo (Aft J V P)

erone) O,O-diethyl phosphorothioate] and Trolene [O,O-dimethyl O-(2,4,5-trichlorophenyl) phosphorothioate] for the control of grubs in cattle began. Co-Ral is applied externally as a spray and is absorbed and translocated to kill the cattle grubs. Trolene is most effective when administered internally. Dimethoate [O,O-dimethyl S-(N-methylcarbamoylmethyl) phosphorodithioate] shows promise in this area also.

Activity of organic phosphate insecticides results from the inhibition of the enzyme cholinesterase which performs a vital function in the transmission of impulses in the nervous system. Inhibition of some phenyl esterases occurs also. Inhibition results from direct coupling of phosphate with the enzyme. Phosphorothionates are moderately active but become exceedingly potent upon *oxidation to phosphates*.

Other types of insecticides Synthetic carbamate insecticides are attracting increased interest. These include dimetan [5,5-dimethyldihydroresorcinol dimethylcarbamate], Pyrolan [3-methyl-1-phenyl-5-pyrazolyl dimethylcarbamate], Isolan [1-isopropyl-3-methyl-5-pyrazolyl dimethylcarbamate], pyramat [2-*n*-propyl-4-methylpyrimidyl-(6) dimethylcarbamate] and Sevin [1-naphthyl-*N*-methylcarbamate]. They are also cholinergic.

Insecticides obtained from plants include nicotine [L-1-methyl-2-(3-pyridyl)-pyrrolidine], rotenone, the pyrethrins, sabadilla and ryanodine, some of which are the oldest known insecticides. Nicotine was used as a crude extract of tobacco as early as 1763. The alkaloid is obtained from the leaves and stems of *Nicotiana tabacum* and *N. rustica*. It has been used as a contact insecticide, fumigant, and stomach poison, and is especially effective against aphids and other soft-bodied insects.

Rotenone is the most active of six related alkaloids found in a number of plants including *Derris elliptica*, *D. malaccensis*, *Lonchocarpus utilis* and *L. urucu*. *Derris* is a native of East Asia and *Lonchocarpus* occurs in South America. The highest concentrations are found in the roots. Rotenone is active against a number of plant-feeding pests and has found its greatest utility where toxic residues are to be avoided. Rotenone is known also as derris or cube.

The principal sources of pyrethrum are *Chrysanthemum cinerariaefolium* and *C. coccineum*. Pyrethrins, which are purified extracts prepared from flower petals, contain four chemically different active ingredients. Allethrin is a synthetic pyrethroid. The pyrethrins find their greatest use in fly sprays, household insecticides, and grain protectants because they are the safest insecticidal materials available.

Synergists These materials have little or no insecticidal activity but increase the activity of chemicals with which they are mixed, especially that of the pyrethrins. Piperonyl butoxide {α-[2-(2-butoxyethoxy)-ethoxy]-4,5-methylenedioxy-2-propyltoluene} and Sesoxane [acetaldehyde 2-(2-ethoxyethoxy)ethyl 3,4-methylenedioxyphenyl acetal] are two important commercially available pyrethrin synergists.

Formulation and application Formulation of insecticides is extremely important in obtaining satisfactory control. Common formulations include dusts, water suspensions, emulsions, and solutions. Accessory agents, including dust carriers, solvents, emulsifiers, wetting and dispersing agents, stickers, deodorants or masking agents, synergists, and antioxidants may be required to obtain a satisfactory product. Insecticidal dusts are formulated for application as powders. Toxicant concentration is usually quite low. Water suspensions are usually prepared from wettable powders, which are formulated in a manner similar to dusts except that the insecticide is incorporated at a high concentration *and wetting and dispersing agents are included*. Emulsifiable concentrates are usually prepared by solution of the chemical in a satisfactory solvent to which an emulsifier is added. They are diluted with water prior to application.

Proper timing of insecticide applications is important in obtaining satisfactory control. Dusts are more easily and more rapidly applied than are sprays. However, results may be more erratic and much greater attention must be paid to weather conditions than is required for sprays. Coverage of plants and insects is generally less satisfactory with dusts than with sprays. It is best to make dust applications early in the day while the plants are covered with dew so that greater amounts of dust will adhere. If prevailing winds are too strong, a considerable proportion of a dust will be lost. Spray operations will usually require the use of heavier equipment, however. Application of insecticides should be properly correlated with the occurrence of the most susceptible stage in the life cycle of the pest involved. *See* Entomology, economic; Fumigant; Insect control, biological; Insecta; Pesticide. [C.A.H., C.F.L.]

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Insectivora

An order of mammals including such familiar forms as the hedgehog, shrew, and mole. The Insectivora are of ancient origin and are difficult to define; they are united by primitive characters that for the most part are primitive for all placental mammals. It is quite possible, therefore, that several stocks of primitive mammals of diverse origin are included in the order. Many fossil insectivores are known, some going back as far as the Cretaceous. The order is usually divided into 8 superfamily groups, 3 of which are extinct. Living insectivores are divided into (1) the tenrecs and their relatives, all Madagascan; (2) the golden moles of South Africa; (3) the hedgehogs (Erinaceidae) and their relatives of Europe, Asia, and Africa; (4) the elephant shrews (Macroscelididae) of Africa; and (5) the shrews (Soricidae) and moles

Th table hows that the latit dinal gradi nts of solat on are appreciably smaller at the earth s s fac than at the out d of the atmo phere Th h gh value of urface ins l tion near latitude 30 N s due n p rt t the small cloud ness i the la g h gh pr ure areas at tho e lat tudes Add t nal l g tudin l ar at ons in i lati n depend on cl udi Th s n ar l t tude 40 N n umm r th a r ge lati n ex eeds 700 ly/day in de t r a d fall to 250 ly/day in th loudy a eas off J pan

Th energy ab o bed at th urface depends al o on the fa e albed Th reflect ity l the sol d earth es with gr und o e Fo e t ab b nea ly all the en gy in ident them Fresh snow n the ther ha d refle t up t 90% of the inci de t n rgy In middle l titude snow albedo may decr e to l than 40% with t me e pec ally after wa m spell l a mod fi d the su f ce G a s fi ld and oth r surfac will ha e int rmediate al bed

The r fle t ity f the wate su fa e of the arth with cl dles kies dep ds t ongly on the s n z n th angl Z The lbedo f r the di ect sol r beam s o ly 0.02 f $Z = 0$ nd 0.13 f r $Z = 0$ It n ea s t 0.35 f r $Z = 80$ nd t 1.00 for $Z = 90$ F r the e larg r l e of Z the w nd may c the albed t de rea An albedo value f 0.17 f r $Z = 80$ with a w d of 15 knot h s bee sugg ted

Wh n ll th f ct a re ons dered the ab rp t by th atm ph r and e th a l a be est m ted s h wn in th l t l ne of the f reg ing t bl It i int e t g to t th t th gr die t f bs bed ad at whi h the dri ng f rc f the l t mil r to the grad t of the ext a terrestr l i l t [S FR]

B bl g aphy F A Berry Jr E B llay and N R Bee (ed) H db ok of Meteor logy 1945 S Fritz, S l r ene gy n l r a d cl udy d y S i M nthly 84 55–65 1957

Inspection and testing

Comm r al p a tic t to spect prod ts for tw d ha t t nd t test pr ducts fo p f rma As a h in p t n a d test re t p n q l ty a t e whi h t m may be a t p qu l ty t l

I p t n th tcal m nat n f p d t t d t m t c nf rm e t appl abl q l ty tand d r pe ficat on A a r ult f n p t n th p d t is th r pt d o r j t d d pend t degre f c f man Be a n p ct i a po t mortem p rati t has ffect th qu l ty f p od ts the in pe t r m ely a pt o j p odu ts f th am q l ty hm ited f n p t on

In pect n an h wei ers s the fir t t p a p g m t ma ta n l ed qu l ty l l (see Q LITY CONTROL) A m ll p t n f the prod ct n pected soon s t i mpl ted th res lt l ed a d pp p ate t nd t rm n d t ad j t th man f t r ng p r t so a t m i ta the desired quality It is this control or continual adjusting of the process whi h assures the produc tion of pr duct within applicable qual ty restric t ons In th s ma n r any de ed level of quality can be ma nt ned and the product on of subquality items can be prevented

Howeve the need a i es to evaluate the quality of p oduct after they ha e been m de and it i no longer po sible t e erci e control o er the produc tion p oce s Q al ty a uran e fill this need Q al ity as ur ce is rel ted t q ality c ntrol but is not synonymous with it Quality a s rance operates after qual ty control when the product is com pleted It u e inspecti n and te ting to evaluate the quality of prod cts and to determin th degree of conf rm n e t applicable standard

In pection is generally a mechanical operat n it determ nes the adequacy of such characteristics as appearan e d me i n and o er all operation of th p oduct Test ng i more penetrating it me su e p rforman e in ne f rm or another Test ng i olves i trumentation to mea ure the function l adeq cy of the product Testing may be u ed to d term e the q lity of ide and aud cha act r t cs f a tel v si n recei r It may be u ed to meas re the load carry ng chara t ri tics f a moto generator set under varying p rating cond ti n Information is obtained on speed t rque load tempe atur and l ad ffi iency character t c

The purp se of s ch testing i th e fold Fir t it i t e aluate produ t f r formanc t applica ble q l ty stand rd Th s i referred to as com mer ial test ng a di ti g i hed fr m a c mplete eng neeri g test f the product S c nd test g is u ed t d sc ver the po sible existence of saf ty haza ds For e ampl le tri al p od ct a e g en an over potenti l test to assur a fety t the opera tor under normal ope at ng c nditions Th rd test ing determ ne the rel ab l ty of the prod ct Relia b l ty is th probab l ty that a p oduct will perform its nte ded fun t n under environm nt l c nd t ons f to age maintenanc d ope at n Life te ts of the produ t a d te ts t de tru ti are u ed to determ ne reliab lity For this pu po tests m de a l m ted numbe of units but the t sts g h y nd omme i l test g

Stat ti al m th ds re ed xt si ly l r e) u ting i pection nd te t results bec se these methods on ey a tremend s amount of inf rma ti n r ga di g ave ge q ality expected range of v riati i qual ty nd l ab lity f the product See QUALITY CONTROL [J M N]

B bl graphy W G H lzbock Inst um nts fo Meas m nt and Co t l 19 5 C. W Ken edy Insp ct n d Gaging 19 1

Instability electrical

A cond t on f unw ted lf-o c ll t n n an am pl fier r t It i us ally au ed by c si e p t f edba from utp t t i p t In a au d o-f eq ncy amplifi the in tab l ty may b at l w and o f equ nc es result g n putt putt sounds

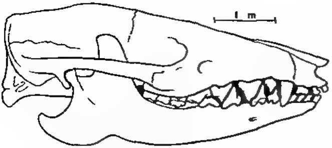


Fig 2 Skull and lower jaw of *Ictops* an Oligocene menotyphlan insect ore (*After W Scott and G Jep se*)

ceous of Mongolia and appear to be primitive relatives of the Leptictidae in which the anterior dentition is aberrant The Endotheriidae (*Endotherium*) occur in the middle Mesozoic of China and may be the most primitive known menotyphlans but they are insufficiently known for meaningful appraisal

Still a third group the Deltatheridioidea most of whose members possess upper teeth bearing only one major cusp or two closely appressed cusps ranging from the Late Cretaceous (Mongolia three genera) to the late Oligocene (North America *Apternodus*) has been placed in the Insectivora in the past but has recently been shown to be more closely related to the Carnivora *See* CARNIVORA FOSSILS

Lipotyphlan insectivores were specialized and gave ri e to no other orders of known mammals The hedgehog supposedly the prime example of a primitive placental mammal since Huxley s day is considerably ad anced over early Cenozoic menotyphlans and all li ing erinaceoid derivatives are even more aberrant The Menotyphla on the other hand gave rise to many orders and may le regarded as the primitive placental stock some of who e member have survived to modern times to live side by side with lipotyphlan insectivores

[M C MC]

Insectivorous plants

These are plant having variou ly modified highly specialized lea e which capture and dige t in ect The proteins of the dige ted in ect bodies supply nitrogen which otherwi e may be unavailal le to the plants in the places where they grow Some times they are al o called carnivorou (fle l eating) plants *See* PITCHER PLANT SUNDEW VENUS FLY TRAP *see also* SARRACENIALES SECRETORY STRUC TURES PLANT

[P D]

Insolation

The amount of solar radiati n which reaches a unit horizontal area of the earth It i tl e latitudinal ariati n of in olation which upplie energy for tl e general circulati n of the atmo phere In olation out ide the earth s atmo pl ere dej end n tl e angle of incidence f the s lar l eam and on the solar con tant The lar n ta t i th amount of energy which in unit time reacl e a unit j lane urface perpendicular to the un rays out i l the earth s atmosphere when the earth is at its mean distance from the sun In olation is mea ured in langleys (ly) or calorie per centimeter quared (ly = cal/cm) A marked winter gradient of insolation exists from clo e to 900 ly/day near the Equator to zero in the dark polar areas but in summer the insolation is quite uniform—over 1000 ly/day near the poles compared with about 800 ly/day near the Equator

The extraterre trial olar energy is modified by the air the clouds and the land and water urface of the earth Energy of wavelengths horter than about 2900 angstroms does not reach the urface but is absorbed high in the atmo phere mainly by nitrogen oxygen and ozone

Air molecules also catter energy in accordance with Rayleigh s law and ab orption by ozone water vapor and other ga es further reduces the olar energy transmitted *See* SCATTERING (ELECTROMAGNETIC RADIATION)

Particles always pre ent in the lower atmo phere scatter and al orb energy too However clouds affect the extraterre trial in olation more than any other atmospheric factor The reflectivity (or al l edo) of clouds varies from le than 10 to o er 90% of the insolation on them The albedo will be higher in visil le light than in total olar energy f r clouds ab orb mainly in the near infrared The cloud albedo depends on the drop ize liquid water content water vapor ntent and thickne of the cloud it al o depends on the un s zenith di tance Z The maller the drops and the greater the liquid water content other thing l eing the same the greater the cl ud all edo

Cl uds al o al rb olar energy Thick arm (high vapor content) clouds al orb more energy than other cl ud and for cl ud of p ire liquid waterdrop the ab orpti n may reach over 30% of the energy incident on the cloud top

The solar energy measured underneath cloud also depends on the reflectivity of the surface An overca t which tran mit 0 4 of tl e energy incident on it when the cloud i over a f re t will tran mit 0 7 f the incident energy wl en it i locate l over a l ighly refle ting now surfa e Thi i cau d ly the multiple reflecti n l etween the snow an l the cl ud l ut the for t still al rl m re energy than tl e now

All the e atmo pl eri effe t will m lify tl distril uti n of tl olar energy whi h reache tl e ur face For xample H C H ight n c mputel th annual al e hown in tl f llowing tal le

Latit di al lation of in lation

Lat t l	0 N (	30 N l	60 N ly/l	90 N y)
I t t ent l	8 0	[illegible]	4 0	3 0
At f ce				
W tl l ky	[illegible]	0	3 0	0
W tl no l l f co	410	410	00	1 0
T t l lw y t (tmos phe i f)	0	30	60	1 0

The f cts do not yet ndicate h w di ectly r in wh t m nn r th g nes may influence de elopment of beha i n any an m l Preformi t po tulate a d ect relat onship between g nes and behavior ep genet c ts p stul te an ind re t r lat onsh p th ough ma y interl ci g f ct s in ganism and dev l pmental tuat n The traditional nat e-nurt re ontro rsy h s wan d instead th em phas s s o the tudy of the r of typical and atyp cal ranges of spe e beha or n evolut on and i ont geny *See* HIBERNATION HOARDI G BE HAVIOR HYPOTHERMIA MIGRATORY BEHAVIOR P YCHOLOGY PHYSIOLOGICAL AND EXPERIMENTAL REPRODUCTIVE BEHAVIOR [T C S]

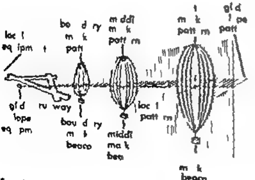
B bl o phy D O Hebb *Th Organ at on f B h i* 1949 N R F M d T C. Schneirla, *Pri pl s f An mal Psychology* 1935

Instrument landing system (ILS)

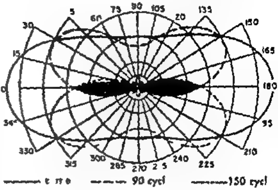
A fixed beam nt uou wa e low app oa h system util zing hf lo l ze uhf gl de- lope stat on and or mo 75 meg cycle marker beac ns Th y tem i also kn wn as nstrument l w approach ystem (ILAS)

In de t m ke a app oach an a rc aft must fly c ur e th t i n l ned f m ome ele at n t the t hd wn p int on a runway Such a cours n be generat d by the inte ction of two planes One f th e pl ne mu t be vert cal nd sh ld c c de w th the ent r li e of the ru way The e d plane sh ld be app oximately h r zontal l ed f om th de ed elevat n to th t uch d p i t f th ru way The erti al plan s g erated by a g und ad stat on alled a local i e Th l ned pl s p oduced by a parate d di tat n kn w a th gl de sl pe sta ti n A th ai raft m es al g th approach ur d tan e t tl tou hd wn p i t i indi cated by the gnals r c ved w th n m ll rea Th gnal a t an mitt d by stat ons called m k be on (se F g 1)

Localizer The lo al zer t n mitte oper te n the 108- t 112 m gacycle b nd It o mally l at d 1000 ft bey d th f r e d of th u w y It feeds a l ne rray on ting f fi e even



F g 1 G Id f m th f d b m l w-app oa h sy t m



F g 2 F ld patt rn f local ze

I iz ntally p lar zed ant nna elements The central el ment (element) in the e antenna arrays i fed with a carr er frequ ncy t gether w th d ba ds of 150 and 90 cycles The other el ment are fed with only the s deband e ergies resulti g fr m 90- and 150-cycle modul t on The energy feeding the el m nt on one side of the array is 180 out of phase with that f ed ng the oppo ite de of the array In spa e the patterns appear as shown in Fig 2

In the a rcraft a special recei er is u ed to detect the local er ignals It output is con ected to filt r wh ch s pa at the 90- and 150-cycle ignals a d ompa e the r amplitude in a bridg circuit The outp t of th br dge is ppl ed to actuate the vert cal needle f an in trument This needle (see Fig 3) m es right or left depend ng on the rel t e nte ity of the 90- and 150-cycle mod lat on ign ls When th edle i entered it ind cat th t reception is b ing obtai ed on a cour e d e tly n line w th the ce ter li e of the runway The ens tivity f th ystem is such that f ll c le defle ti of the needl i obta ned when the ai craft is only 2½ off the cent rl ne

A sociated with the ertical c o s poi te instru ment i a sm ll additional pointe marked w th the letters OFF This indicator ctuated from the um f th 90- nd 150-cy le signals Whene r the 90- r 150- ycle signals o both ha suffi ie t inte ity th s indic to i retract d to a pos t on wher it is no lo g r s ble S nce th ndic t on of th ert cal n edle i the s me when b th s gn ls re equal or both g al are ab ent the w ning fl g nece s ry t inform the pil t wh th r th nt ed needle ndi at equal ign ls r their ab n

The effect f flection from ite may be mini m z d by educ g the beamwidth of th rad ated p tt rn The f e a m dern a tenn d sign em ploy as many 12 elements form ng an a ray w th a l ngth of n a ly 80 ft Th ent e d ecti l l s tha 15 S nce thi p tt n s incapable of fu sh ng gu dan e when aircraft i off urse mo e than abo t 7 n add t nal rray f d by a econd t an m tte i employed Thi sec nd array

called motorboating or at ultrasonic frequencies that cannot be heard but cause distortion and a drop in efficiency.

Instability is a much more serious problem in higher frequency amplifiers, particularly microwave amplifiers, because the excessive positive feedback can be caused by the very small capacitance between two adjacent connecting wires, by the capacitance between a component and the metal chassis, or even by electron tubes operating at incorrect working voltages. See AMPLIFIER.

[J. M. R.]

Instinctive behavior

Any species-typical pattern of responses not clearly habitual or acquired through experience. This wording is preferred to the traditional term instinct, which denotes an innate impulse blindly impelling action appropriate to attaining certain end. The adjective instinctive is used by some, the Freudians for example, to signify certain complex motivated behavior and thus leans toward the classical meaning, that of an innate drive or predisposition to given acts.

The problem In every animal species certain characteristic patterns or systems of adaptive action appear under certain conditions. Thus many spiders spin webs typical of their species, most birds make species-typical nests, and beavers build dams and lodges. These activities, instinctive in the above sense, pose important questions concerning their evolutionary basis and genetics, their ontogeny and psychology, and their adaptive significance.

Criteria Earlier theorists, seeking objective approaches to this problem, devised certain criteria of the instinctive in behavior, particularly appearance shortly after birth or hatching, nonessential dependence upon learning, and appearance in the individual raised in isolation. With further research, however, these criteria all met with objection. For example, the first is contradicted by evidence that species-typical behavior may appear at stages other than birth, the second by evidence that experience and learning often exert their effects in ways resisting clear identification, for example, embryonic stimulation or prenatal conditioning, and the third by the fact that isolation may not exclude extrinsic influences, that is, stimulation properties of the individual itself, which are characteristic of the species. But the last two of these criteria still influence many students of comparative animal behavior who synonymize with instinctive such concepts as innate nature and endogenous.

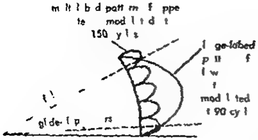
Focal points in research and theory Objective study demands that the behavior patterns of representative animals be studied analytically and that basic assumptions be tested. Research must cover environmental conditions and stimuli, the range of behavioral variation, and organic conditions underlying the development and appearance of the behavior. Both longitudinal and cross-sectional studies of behavioral ontogeny are needed, obtained by methods appropriate to the species and their genetic controls.

In theorizing, all conceptual terms must be evaluated. Thus skepticism about the instinct concept centers around traditional dogma which differentiates psychologically between man, conceived as the sole possessor of reason, and lower animals ruled by instinct. This idea is contradicted by much evidence in comparative psychology. The related assumption that animals possess an original innate nature modified only secondarily (if at all) by experience is opposed by evidence on behavior development. The related idea of sharply distinguishing instinctive from intelligent behavior is in contrast to evidence that instinctive behavior is often plastic in relation to the situation. Differences in the nature of such behavior and in its developmental basis doubtless exist on different phyletic levels.

Other unsettled controversial points in research and theory concern the role in such behavior of (1) neural organization, (2) nonnervous organic factors such as hormones, and (3) sensitivity and perception, together with the relation of these in ontogeny (development). Some authorities postulate the existence of innate central neural coordinations to account for the rise and control of instinctive behavior; others emphasize the role of peripheral mechanisms interwoven with neural processes in behavioral ontogeny (see BEHAVIOR, ONTOGENY OF). Classical distinctions between reflex and instinct are questioned on the ground that such functions may differ in degree rather than in kind. Theories distinguishing sharply between instinct and learning meet the objections that neither of these is sufficiently well understood and that both may vary greatly in their forms and in their relationships to development on different phyletic levels.

Although all behavior is related to heredity, the influence of the genes upon behavior is a complex question still unanswered. Genes in the chromosomes must exert basic influences on structural growth and through structure on behavior (see BEHAVIOR AND HEREDITY (GENETICS)). Examples of behavior determined or influenced by structure are readily found, as in limb structure and characteristic gait, cellular equipment in the retina of the eye and proneness for day or night activity, size of certain glands such as the adrenal, and degree of docility or of wildness. However, it is another matter to trace out such correspondences from the fertilized egg through the complexities of ontogeny.

The genetics of some of the species-predictable behavioral characteristics of animals have been worked out and are impressive. Thus, through selective breeding of parental generations, it has been possible to produce hybrids and backcrosses of certain insects, fishes, birds, and mammals differing predictably from the parents in behavioral characteristics such as level of excitement, parental behavior, and reproductive behavior.



Fg 3 M th d f p d g q g l gl d p th by m of t e t g field p tt s d t d f m tw o t s l sp fi d dff t h ght b e th g d (ILS)

The powe of thes beacons is of th order f 3 atts d th y a c nected t ant nna ystems ns t g of everal in l ne full wa e lements h ch pp the ad at on lo g th ppr ch path nd th by nf t to arr w a ea alo g the path d a w d a at gl t angle to the p th In the a r aft a ep ate y tal nt olled ec r of l w en t tv s util ed pecif ally fo th ec pt n f the m ke beacon gnal Th outp t of tl i e s onnected to uitable filte wh ch th actuate th ee l ght In me i tall t on a i gl l ght s mployed nd tl re f e the g l f om the thr m rk rs are n t pa tely d nt fied Se NAVIGATION SYSTEMS ELECTRONIC PRECISION APPROACH RADAR (PAR) [P C S]

B bl g phy J S Hall *Rad A ds to Nat ga tion* 1947 P C Sa d tt *El t on At gat on Engi n g* 1958

Instrument transformer

El t t a fo mer pecifi lly de igned f u e n m a u eme t d nt l uit Tl p p e of st m t t n fo m t n e t pr mary lt ge ts t eco dary al s s table for th r lay met r r ther m su g equip me t A ond pu p to late th h h olt ag p m c t f m the m s ment Tl th tr t f mea r ng de c d the pr tect on f p n el s ng su h d i e gr tly mpl fi d by th e f int m t t ns f m r A k t h how g tf ba lem t d rl so d agram for n trum nt tr nsf rmer i h n n Fg 1 F gene al d u o f tra f rm TRA SFO R

Spec l d design t hn qu a d m t al e ed n t um t t f rme t t ur a high de f t bil t a d l b l ty bec se mpr p op r t n uld e ult n mic l mete i g ppl at r p we y tem d mag r r lay ng ppl at

Tl e a tw g al typ f n t um nt tr ns f rr n tr me t p t nt al tr f rm which a ed ltag m a u m t a d t tr ment r t t n f rm wl ed n r nt m r m nt

Tl pr m r f pot t al t an f rm r i n ted th l nd th e t that fl w thr ugh thi winding produces a flux in the core S nce th c re links both the primary and econd ary w ndings a v ltage s induced in tl e e ondary ci uit The rati of primary to secondary voltag s roughly in pr porti n to the number f t rn in th p ima y and secondary w ndings Usually this rati is sel ted to produce 115 or 1 0 volts at the secondary term nal when rated v ltage is applied t th prima y

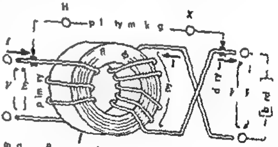
The curr nt tra sform r differs from the poten tial tran former in that the primary winding is de gned for nnection in s rie with the line The ratio of pr m ry t ec ndary current is roughly inver ly proporti n l to the ratio of primary to seconda y turn Usually 5 amp re ec ndary cur rent is p duced l y rated urr nt in the primary

In trument transf rmer may differ considerably since the pl y ical n t struction depends upon tl e int nded appli ation A potential tran f rmer u u ally has a n agnetic core nd c il a rangement th t s quit imilar to that f the con ent nal p wer d t ibution tr nsformer Since the core per ates ontinu usly at the highest flux de ity con s tent with good magnetic d s gn the core is tl e maj h at prod ce Tl er f re hell typ c n t t on u ally is empl yed for effecti e heat dis p t n

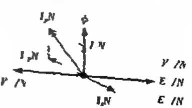
In a curre t tr forme the magnet c c re den sity i a fun tion of line current nd except for c s onal t an i nts cau ed by l ne faults n usu lly ery l w The c re los s negligible and the windi gs are the maj ou ce f h t Theref re th o e type of con tru tion s g n rally empl yed

Spe i l n ulati ns u h as arc r si tant b tyl rubber ha e b en de elop d for wind ng n ula t n to en ure nec ry reliability nd afety

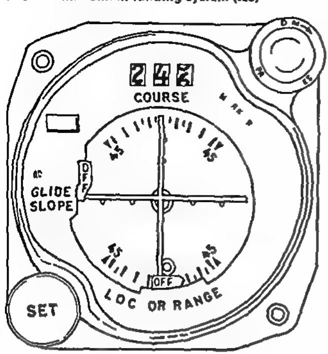
Instr ment tra forme s ha e a marked ratio wh h diff r fr m the turn rat and m re nearly



m g fl f om g



Fg 1 A mpl t m t t fo m d ts ph o d g m l th ph s *dag am th* e d m p ts d mp d t d op h m tt d f mpl f t (F m J F K d Appl d El ct l M m t W l y 1956)

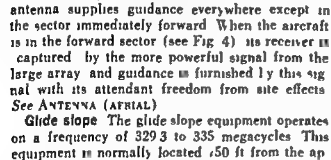


Fg 3 Modern ■ oss po nter instrument A ma ker beacon l ght ■ mounted in the upper right hand co ner

employs only three elements and ■ fed by a transmitter operating 10 kilocycles from that feeding the main array This transmitter and its a ociated antenna supplies guidance everywhere except in the sector immediately forward When the aircraft is in the forward sector (see Fig 4) its receiver ■ captured by the more powerful signal from the large array and guidance ■ furnished by this signal with its attendant freedom from site effects *See* ANTENNA (AERIAL)

Glide slope The glide slope equipment operates on a frequency of 329 3 to 335 megacycles This equipment ■ normally located 750 ft from the approach end of the runway and approximately 450 ft from it center line Twenty channels are provided in this band Antenna arrays utilized with the glide slope system are of two general types the equisignal sy tem and the null type system Signals from both sy tems are capable of producing satisfactory indications when received by equipments with similar adju tment Both y tem utilize the earth a a reflecting plane

Equisignal system In the e ui ignal sy tem the tran mitter output ■ modulated with 90 and



Fg 4 Local ze feld pattern showi g d cto ol p t t rn fo forwa d ecto app oach ■ d gu da ce fo all other sect

150 cycles The carrier and idebands re ulting from the 90 cycle modulation are fed to a horizontally polarized antenna located at uch a distance above the ground that only one lobe is formed in the space used This height is approximately 6 ft for glide slope angles of about 2 The carrier and sidebands resulting from the 150 cycle modulation are connected to an upper antenna located at a height of approximately 28 5 ft This antenna generates five lobes in the ame space as the ingle l be of the 90 cycle signal (see Fig 5)

In the aircraft a special receiver is u ed t receive the glide slope signal At the output of the receiver the 90 and 150 cycle are separated by filters and their intensities compared by a bridge circuit The output of the bridge is connected to a horizontal needle on the in trument previou ly described (ee Fig 3) The deflection of the needle upward and downward indicates the vertical po ition of the aircraft with respect to the optimum approach path As is the practice with the localiz r signals an auxiliary OFF indicator ho that the centering of the needle ■ actually cau ed by the sufficient inten ity of the 90 and 150-cycle glide lope signals and not by their al ence

Null type system The pattern of the ignal from the lower glide slop ■ antenna i affected by precipitation To minimize this effect the null type sy tem has been devi ed In this sy tem the upper and lower antennas are fed with carrier and sideband signals re ulting from both the 90- and 150-cycle modulation The upper antenna i located at a height of approximately 33 ft for a de ired vertical angle of approximately 5 and produces two l bes Because of the reflection phenomena the ideband of these two lobes will l e in oppo ing pha ■ The l wer antenna is located at exactly half the height of the upper antenna thu it pr luce a single lobe with a maximum at the same angle for which the upper antenna ha a minimum Deviati n from the glide l pe po ition cau e the 90- or the 150-cycle inten ity to increa ■ greatly th i cau ing the needle to l fle t either upward r d wnward A deviati n of only ne half degree fr m tl e n rmal p ition pro l i ■ a trong deflection The l er antenna n w l eing at a height of 16 5 ft (rather than 6 ft) i relativ ly unaff te l l y hang in tl height of the gr un l plan l ie t precipitati n Sn wfall a l igh a 2 ft ro lu ■ cl ange in path angl f l than 0 13

Marker beacons T in l t progre al ng tl appr oa l path there ar thr marker l a n Th tran mitt r per ting ■ 5 mega ycles c nf ne tl eir ra liati n larg ly t th erti al d m n i n u ing nly mall area f tl h riz ntal pl n Th ter m rk r i l at l at a l tan e l appr ximat ly 4 mil from tl l n lary f tl airf l l an l i m l l te l at fr q n f 400 cy l A mi l ll mark r i l t l ppr imat ly 3 00 ft fr m tl appr ch n l f tl runway and i m l l t l with a fr n y f 1300 ycl Tl inn r mark ■ l c t l t tl l n lary f tl airfiel l i m l lat l with a fr f 3000 cy les

m t an el the ppl ed oltage V_p t polar ty s determ ned f r all turns includ ng the econdary

$$E\ /E = -V_p/V = N_p/N$$

In trument tr nsf m s ha e polarity marks uch th t wh n the c rr t enters the H p imary t t nta u ly lea es th X e ndary and f H h p ti e p tential X s al o p ti e

Clos the ee nd ry circ t of n deal t an forme res lts n a ondary c r ent i with an mmf $\mathfrak{F}$ n the prod c n a magnetizin f ce H

$$\mathfrak{F} = N$$
$$H = N_s i /l$$

he e N i the number of seco d ry tur and l th m gn t cu t length

Thi magn t zin f must exa tly ancel that of the p m ry a n e n ex t tion fl x m needed f th ideal t an form r

$$N_s\ /l = -N_p\ /l$$
$$i = N\ \ N$$

Whe n defined a $-N\ /N$ the foll wing r l t n n l x ed

$$i = \ _p n \qquad E = -E\ / \qquad V = V\ /$$

Wh n th co dary r it i l sed the seco d ry current $V\ /Z_b$ wh Z the sec ndary bu den (the l d a d it wi ing) e mp ed f re t anc R and r a t n e X_b

An ctu l in trum nt t ansformer an be s mu l t d by the two k h n in F g 2a S m am pe e t rn needed m p oduce exc ting fl x i th m gn t c u t A ur e t I thr ugh N turn p od es th fl it has a mag et zi g c mp n nt I d an eddy rr nt and hy t res s watt l s comp e t I Th ar imulated n th equ va lent cu t by acta e X_m and a r istan e R_m r pect ely The t sf m w nd ng l resi t n h w by R d R nd mag ti l akag prod es mall e t n es sh wn by X nd X Eq l t i u t l mt at g th d al transf me b d awn by el m g all al es t th ec nd ry a F g 2b o t the pr mary in F g c

R l i r r i rr g q ant t s fr m the pr mary t th cond ry a (1) mult ply I by ( ) d d I a d E i y nd (3) d d Z_p, R and X by n

Th se q l nt irc ts e lly s t fa t ry to pred t t n f rm pe f rma alth ugh m th t f m th m gn t zat h r t tc s o l n a Cap t i eff ts l ex t Thes h uld be ev l ted at f equen ies bo 100 p d t i u lly nec ty t hang al f X_m d R a f ti n of f qu n y

Accurac es P r t al t f rm r ee a e de pe d n th m gnitud f primary and econdary ltag d pe W th the ndary pe r uted th l ltag d p au ed by th xc t g u t W th a b de it po bl t dd d op d to the b d n t both pr ma y d c d ary t obtain the over all change in performan e

I tent al tr nsformers are de igned to ha e low ex c t ng cu rent and l w winding impedances

In a cur ent tr n form r the differ nce between the eco dary and p imary current i the exciting cur ent The ef re small err rs in both ratio and pha ngle ex st fundamentally These errors ary with p nary curr nt and many c mpen ating che nes ha e be n u ed to increa e accuracy B th th magnet zing and ore l s urr nt are k pt sm ll spe ial lam nat n mater al is u ed n l spe cial techniq e are u ed t r d c lo es in the t an former

Comm rcial i st ument tran formers have ex trem ly g od ac ura i ard manuf cturers f rni h typ al curves dep ting an mall err r *American Standard f r Transformer Regulat rs and Reac to s (ASA C57)* p cifie the accura y cl es for pec fic bu de s and err r a e kept w thin thes tanda d ac ura ies for transf rmers of a gi en cl ss Fo eve gre t r ac ur c es test equipment i a ailable f r accurately mea uring ratios and phase a gl s by e ther d rect method or by comparison w th standa d transformer S e ELECTRICAL MEASUREMENTS [I F K]

Bibl og aphy I F K nn rd *Appl ed El ctr c l M asu em nts* 1956

Instrumental analysis

The u e of an instrum nt to me sure a con pone t *to detect the c mplet of a q ant tati e reacti n* or t detect a change in the pr pert s f a syst m

The p e nce f a m asu able chara te ist c h h s unq ely d p de t upo the concent a t on f th sub tan e t l det rm ed i requ red This har cter tic ca be ab orpt or em s n f rgy radi act vity x dat n or red ct n be havi nuel r or lectro ic p op rties *magnetic* beha o r the mal p op rties The charact risti sh ll be easily m as red and h ld be s mply related t the am u t of mater al $\jmath$ nt Ex ampl s of thi appl at a e the d t rmi ati ns f rad um in es by rad oactivity naly of tung t n m t el by m n spect oscopy f it m A by ult ol t absorpt n n l of coppe i l l gi l mate i ls by pol ography In two c mp nent ystem a p operty of the sy tem a a whole can ften b m a red and related to the d i ed omp ne t For ample a water ethyl alcoh l mixtu n be analyzed by de ty r r fra t i d x m a rem nts For a ample c ta n g comp nents n — l ep rate me re ment are nec sary

An in t um t an b u ed t dete t the mpl t on of q t tat e r t n when imple meth ds, ch s v sual i d ators, a e not appl able U ually ch ract ri t f the ubst ce be ng d te m ed f the e ent me r d An example th mpe om t c titr t on of ulfate n th lead on whe e th fi t e c s f l d b yo d th e d po t s d tect d b its el ct ly c n du tio cur nt

represents the true ratio of output to input However since the true ratio changes slightly with burden frequency temperature changes and other factors the marked ratio must be multiplied by a ratio correction factor to give the true ratio under specified operating conditions

Principles of operation In trument transformers approach an ideal transformer and their principle of operation is explained by a study of the ideal The practical differences from the ideal can then be incorporated and equivalent circuits can be es tablished which allow analysis of most instrument transformer problems

In the ideal instrument transformer the output voltage or current is exactly proportional in mag nitude to and exactly opposite in phase to the corresponding input voltage or current This means there is no core or winding loss and no resistance or reactance voltage drops All the flux links both primary and secondary windings

An alternating voltage applied to the tran former produces a primary current and a resulting alter nating flux ϕ in the core The ame alternating emf e is induced in each primary and econdary turn b the changing flux linkages $d\phi/dt$ For a complete winding the induced voltage e juals $-N(d\phi/dt)$ where N is the number of turns

The instantaneous flux ϕ in an ideal tran former is sinusoidal with a maximum value of ϕ_m when the applied voltage is sinusoidal

$$\phi = \phi_m \sin \omega t$$

Therefore $$e = -\phi_m N\omega \cos \omega t$$

The root mean square (rms) value of the voltage i

$$E = 4.44\phi_m Nf$$

where f is the frequency This induced voltage i determined only by the applied voltage and the number of turns since there are no other voltage drops Since the induced voltage in the primary E_p

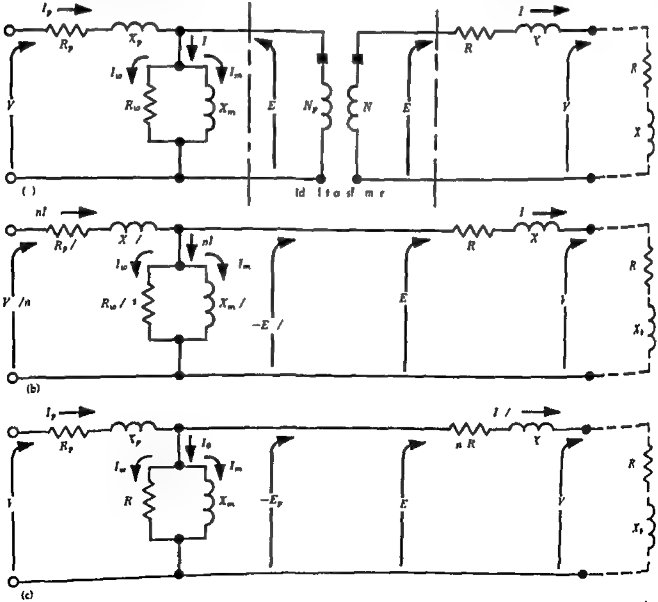


Fig 2 (a-c) Inst ment t a sform r eq i le t ci cu t In (b) all qua t t es are ref r ed to seco dary a d i (c) they a ef ed to p im ry (F om I F K d Appl d El ct l Mea me ts W l y 1956)

ured or controlled by the instrument, such as flow, temperature, pressure, force, displacement, level, velocity, acceleration; electrical quantities (voltage, current, resistance, capacitance); or optical quantities (transmission, glare, color, and brightness).

Another method of designating or classifying instruments is by the operating principle. Examples of this method are x-ray (microscopes, diffractometers), spectrometric of various types for various portions of the frequency spectrum or particles (including infrared, ultraviolet, visible, microwave, x-ray, γ-ray, neutron, electron, and alpha particles), mechanical, electronic, electrical, magnetic, hydraulic, nuclear, acoustic, optical, and photographic.

Each of these methods of classifying instruments is useful only in specific instances. A single instrument or instrument system may use a combination of different principles. A general instrument itself has many applications. Any physical quantity may be measured by a number of different principles. Each of the many operations performed by an instrumentation system may be accomplished by a number of different [illegible]. Thus no single method of classifying instruments is possible, and these several methods are used where they apply.

In this encyclopedia, some articles have headings according to one of the classifications listed above, depending on common usage. Because of the many articles dealing with instruments and measurements, it is impossible to list here all articles that are concerned. Most instruments that measure physical quantities or properties are discussed in the article describing that property. Other instruments used in a particular field may be found by consulting the article on that field. Specific instruments may be the subject of separate articles, and these may be found by consulting the index.

Scope of instrumentation. Instrumentation in its total scope includes the development of instruments and components, both individually and in integration with associated devices into instrument systems, to perform many of the functions mentioned above.

In many instruments, matter or energy in fields is modified by the quantity to be measured, and the modification is detected and measured. An example is an x-ray beam which penetrates a specimen; the intensity of the beam is dependent on the density of the [illegible]. An ionization chamber [illegible] transform the ray [illegible] the point [illegible] a meter. [illegible] pumps, [illegible] tubes, batteries, signal generators (oscillators), sound and radio sources, high-voltage electron or ion accelerators, wind tunnels, and shock tubes are all examples of equipment used to provide such auxiliary fields, beams, or conditions.

The general physical and mathematical principles underlying the operation of instruments and instrument systems are drawn from all branches of physics and engineering, primarily from physics. Instrumentation as a science is concerned with the development and study of these principles and techniques, their application to the design of specific instruments, and the utilization of instruments in research, engineering, testing, industrial processes, communications, defense, education, and other areas.

All instruments have inherent deficiencies. These deficiencies are broadly described by accuracy and precision characteristics of the instrument. Accuracy is the degree to which the measured value approaches the *true value.* Precision, which may be regarded as *potential accuracy,* relates to the capability of the instrument to distinguish one value of the measurand from other nearly equal values when the measurements are performed separately in space and time. No instrument responds instantaneously to a change in the measurand, and the lag is dependent on the nature of the frequency of the instrument system and its degree of damping (internal dissipation of energy). If the damping is too great or the natural frequency too low, the response may be excessive and the indication of output is seriously in error during an interval of several times the natural period of the system. Conversely, if the damping is too small, the dynamic response may be excessive and the output may exhibit oscillation before attaining the desired steady value. In either event, additional analysis of the instrument characteristics [illegible] appropriate corrections.

Many instrument elements exhibit drift, a slow change in properties with time resulting in a change in output. Many elements also exhibit the phenomenon of hysteresis, that is, they exhibit a response to increasing signals which is different from the response to decreasing signals. Environmental effects such as temperature, pressure, and vibration may also affect performance of certain elements. The instrument maker must know materials and operating principles which minimize these effects. The user must develop measurement techniques which either minimize these effects or correct for them.

Instrument systems are set up in the physical systems with which they are associated. In many instances, the presence of the instrument, or its interaction with the existing field or signal element, or measuring instrument may undesirably disturb or change the quantity to be measured. In automatic control the instrument system must be precisely [illegible] the physical system.

In automatic control systems the value of the variable to be controlled is compared with a desired value, and the difference (error) signal is utilized

Instrumental analysis does not require the appearance or disappearance of a characteristic. It can be only an increase or decrease. An example is the pH titration of a weak acid in water where the change in hydronium ion concentration is measured using the change in potential of an electrode in the solution.

Automatic instrumental analysis is applicable to any system. For example, an infrared analyzer can be built into a pipe through which a process stream flows. After the relationship between energy absorption and concentration has been established, the device reports the concentration to the control room and, in addition, makes a record on a graph, all without human supervision. Instruments can also be used to remove a measured quantity of sample, to titrate a given constituent, to clean the titration vessel, and to report the analysis with no help other than the providing of standard reagent solutions and the selection of proper equivalence point conditions. [K.G.S.]

Instrumentation

Designing, manufacturing, and utilizing physical instruments or instrument systems for detection, observation, measurement, automatic control, automatic computation, communication, or data processing. Loosely, the term instrumentation is also used for the ensemble of instruments and auxiliary equipment used in an experiment, test, or process.

Instruments and instrument systems. In the broadest meaning of the word, an instrument is any device useful in accomplishing an objective. Scientific and technical instruments (to be differentiated from surgical, musical, and legal instruments) are devices used in observing, measuring, controlling, recording, computing, or communicating.

Instruments and instrument systems refine, extend, or supplement human faculties and abilities to sense, perceive, communicate, remember, calculate, or reason. The human senses by which we feel, smell, taste, see, hear, maintain balance, estimate distance, and the like are refined or extended by such devices as surface roughness and contour gage, micrometer, chemical analyzer, pH meter, microscope, telescope, gyro-stabilized platform, range finder, and many others. Other instruments such as magnetometers and cosmic-ray counters sense or measure physical quantities for which there is no physiological sense developed in human beings. Other instruments (such as cameras, correlators, simulators, and computers) perform functions of storing, transmitting, or processing information signals in ways analogous to or going beyond human abilities to record, remember, communicate, compare, count, and systematically apply logical operations.

The simplest instrument merely provides a material standard with which the user can compare a physical quantity, as in measurement of length by a yardstick. Transducers are instruments which transform the quantity under observation (the measurand) into another quantity for which a standard of comparison is more readily or easily available or which may be transmitted further, transformed, recorded, or otherwise processed for utilization. A liquid-in-glass thermometer transforms temperature (the measurand) into position of the liquid in the stem with an attached scale calibrated in temperature units.

The signal—a condition, quantity, or magnitude generated by the transducer as representative of the measurand—may be transformed a number of times and in a number of ways in an instrument system. For example, temperature may affect the position of a bimetallic strip whose movement may change the electrical capacitance in a circuit, thereby changing a frequency or voltage which may control the duration of a radiotelemetry signal (pulse duration modulation). The telemetered signal in turn (after transmission, reception, and demodulation) may be transformed into current in a galvanometer which changes the position of a light beam on a photographic film for recording, or it might be transformed by an analog-to-digital converter into a pattern of signals for use in a computer, or the signal might actuate a servomotor or a relay which would adjust the input of heat into the region of the bimetallic strip to control temperature.

Each of the many transformations of a signal throughout an instrument system may result in some additional lag and often in a loss in accuracy, but may be justified by convenience or necessity and even by improved over-all system accuracy or response characteristic.

The following list includes some of the more important functions of instruments or components of instrumentation systems in creating or handling signals (or information or data): excitation, generation, modulation, detection, comparison, amplification, differentiation, integration, attenuation, conversion, switching, counting, scaling, timing, programming, correlating, linearizing, correcting, displaying, recording, reducing, analyzing, computing, and controlling. Since all branches of experimental science and technology depend on instrumentation, specialized instruments with a corresponding body of knowledge and practice have been developed separately in many fields. Thus, chemical instrumentation, aeronautical instrumentation, medical instrumentation, optical instrumentation, and many other similar terms indicate areas of specialization in various industries or professions.

Instruments are sometimes classified according to the field of purpose or application, such as navigation instruments, surveying instruments, or oceanographic instruments; according to their functions in instrument systems, such as detection, measurement, recording, computing, controlling, signal modification, or display; or according to the physical quantity or property that is to be measured

Jo example th explo tion of space gene ation f power bv nucl ar eacto s and determination f high temper t re p perties of mat rial presents new in trument ti n pr blems In general in strumentat on resea ch eeks t atta n highet accu ac e greate ns ti ute capability of mea uring xtreme alue applicability under tr m cond ti of u and c p bility of re l ng changes o eff cts that occur at extremely high peeds, su h as nucl ar ph nomen S e PHYSICAL MEASUREMENT

The tre d to wider use of in trumentation for a t m ti m asu ement and ntr l n industry s c ntinually ac le at ng and whol n w ndu trie a e eme gi g wh ch uld t xi t without highly soph ticated n trument ti n Th s trend will on tinu st a rat l mit d only by question of co t fety and reliab l ty Reliab l ty part ci larly of electr c compo e t h been r us problem but w ll imp o e as a es lt f devel pm nts in solid t te c cu t lement new mate als new techniqu a d m r att nti n t e all syst m e gine ng S RE IABILITY OF EQUIPMENT

An ther gn fi ant t end i th increa ng ut l zati of dat pr ce g devic s r o der c m p te s and sim la qu pme t for automati rting sto and p d elect etric al of i formati n and nume ical data in nk ng a counting and doc ment t on S milar de es r be ng adapted fo autom t e d g, l ad ng t aut matic lan guage t an lation

Compute theory s b ing extended t the de ign of log c m h nes and elf-organ ing ystem whi h may imul t not nly th pr ces es f r m mbering a d e on ng but al o the p oces f lea ning M re e ten on f speed and cap ity w ll soon make f as ble th u f ompute t com p te w th r predict on f m analys s f meteoro l gic l d ta f om a wo ld w de ob erv t n n t w k t an lyze a d f eca t n m tre ds to a se s l g ti r qui m nts and m l tary c pab l t a d to p ed t th pr b ble ut ome f mil t ry t es or pol t cal c nt ts.

In the med l fi ld trument t on f r a to m ti te t ng f phys ol gi l bioch mi al d n rolog cal pa m te now ba ly me gi g b t ert n to b om w d p ead Correlati n dev c re b g devel ped d agn t and l n l n t m t fo locati n a d ident fication f nt m l ll r m lt plyi g in numb r d p et n

In educati a di s u l in t m nti re bei g dev l ped int s vely Supplem t d by a tomat c ti devi es nd other trum nt for le rning th p m gr ti re es the ffi ency f the hole educ t l y t m [W A W]

B bliog aphy W G B l (ed) *Phy c l M th od Ch mi al A aly is* ol 1 1950 H Ch st t, d R W M y *S te m cha i ms d Reg l i g Syst m* 19 1 D M Con d ne (ed) *P s l t m nt d Cont ol H db ok* 19 B C D lahook *I d tri l C t l I st u m nt* 1956 C S D per W M ka a d S Lee *Instrument F gineering* 3 ols 195? D P Eck man *Indu trial Instrumentation* 1950 E M Grabbe *Automation in Business and Industry* 1957 E M Grabbe et al (eds) *Handbook of Automation Computation and Control* 3 ols 1958 I A G eenwood J V ldam and D Mac Rae *Electronic Instruments* vol 21 1948 F K Ha ri *El ctrical Measurements* 195? I F Kin n rd *Applied Flectrical Measu ements* 1956 Arthur Little Inc *Electronic Data Processing Indust y* 1956 G J Murphy *Basic Automatic Cont ol Th ory* 19 7 M H Nichols, and L L Rau h *R di Telemetry* 2d ed 1956 H C Rob rt *M chanical Meas rem nt by Electrical Meth od* 2d ed 1951 T N Whiteh ad *The Design and Use of Instruments and Accurate Mech nism* 19 4

Insulation electric

Mat rial of h gh resi t ity u ed t confine the elec trons in a cond ct r o t may gu de them to a me u ful de ce. For electric wiri g the ins lation is l m ted t fairly flexible types

INSULATION REQUIREMENTS

Th applic t on f insulations ar o varied that ch ice must b made aft r con deration of the nece a y pr pert es and the w ak es es of the in sul t on, nd f th pe ial circum tances of in tallatio No in ul tio ha all the ad ant ges the nsulati n sh ld be so ho n that ts dis d a tages a e not a d t iment in the spec fic applica t on

M y de rable characteri t cs are t perma nt. Th ref re the p opert es of th materi l after a per od of ye rs n the en r nmental onditi ns must als be known New mate als requi e time t devel p their unf reseen weaknes es

Electrical requirements These vary with u e pecific op rtie of te est depend upon the ap plica n The import nt properties of insul ti n are d cu sed b ief Se DIELECTRICS

Re isti ty Comm nly m a ur d as n ulati n e s ta th s is ba ed on a dir ct-current m a urement of fl w into the in ulat n afte el ct ifi a ti n of l m n The curr nt uld b mall nd the i ul t n e i tan e large In t elf it i not per hap th mo t imp rtant ch ra te i tic but d te o rat on i oft n f und to oc ur fa te in low in ula i on r s ta ce m terials und r weathering condi ti s It is a *aluabl mea* of c nsi tency and un f rm ty in m nufa *re If* in service it hould d p bruptly r f ly r p dly ervic fa lu is l k ly to f ll w

D el ct c st ngth Th pr perty d termines the b l ty of th s lat n t re i t pun tu by elec tric pot ntial It is ad ely aff t d by we ther i g o aging b h gh temp rature by tin ed heat and by the ent ance of mo tu

Pow fa to Th s is a me sure f the p we lo n the l t n and hould be l w A rap d n ea i a da g r gn It i import nt in h gh ltag cables but u important low olt ge c bl e ept thos u ed for mmun tion It

to initiate corrective action. Since the output measurement is used to control the input, such systems are called closed-loop or feedback control systems. For discussion of the use of instrumentation in control systems see CONTROL SYSTEMS; SERVOMECHANISM.

If the response characteristics of the instrument system are not appropriately matched to those of the controlled system, the parameters of the combined system may exhibit transient or sustained oscillation. The general problem in design or analysis of automatic control systems is to determine and obtain the instrument performance which will ensure the optimum speed of response consistent with stability. For linear systems (those for which output response is proportional to input) this may be done analytically. Texts on instrument engineering, servomechanisms, or mechanics describe the several mathematical procedures commonly used for analysis of simple instrument measuring systems and control systems. For nonlinear systems, digital computers may provide solutions of acceptable accuracy.

Analog computers or simulators provide rapid nonanalytic solutions for behavior of linear (or to some extent nonlinear) systems under various conditions. Both types of computer are not only used to study systems but are increasingly included as part of systems whose behavior they predict and control. Digital computers also find major uses in rapid storage, retrieval, and processing of data of all types and for solving scientific problems of great complexity. See COMPUTER.

The entire field of military technology rests largely upon modern developments in instrumentation, many of which in fact resulted from military needs. Radar, sonar, and infrared detectors are used not only for detection but also in combination with computers and control systems for automatic guidance of weapons. Homing torpedoes, self-guided missiles, and computer-controlled antimissile missiles are examples of the radical changes in methods of warfare resulting from instrumentation whereby warheads are automatically guided to, rather than merely thrown at, the enemy.

Instrumentation for measurement of nuclear radiation is the basis for all military and peaceful uses of atomic energy and radioactive isotopes.

Thus the scope of instrumentation is nearly universal; it may well be called a common denominator of all of science and technology.

Related fields. Because of the universal scope of instrumentation, there are many fields that are closely related.

Systems engineering. This term is applied to the design or analysis of processes or machines as systems as well as to *instrument systems*. Instrumentation systems primarily involve the flow of signals (information), whereas the physical system or process involves primarily the flow of energy, material, or both. Since the same general laws apply to all physical systems, and since instrument ... are critically in...

neering is a large and necessary part of systems engineering in any field, such as aircraft, missiles, oil refining, steel rolling, and communications. See SYSTEMS ENGINEERING.

A fundamental part of instrument system engineering relates to the theory of automatic control and to the practical application of automatic control equipment.

Information theory. This body of mathematical and logical knowledge, developed for analysis of the efficiency and the limitations of communication systems, is broadly applicable to all types of signals or data, and is thus important to instrumentation. In any instrument or system the output signal varies to some extent in an unpredictable manner because of disturbing influences, some of which may be inherent in the instrument or system. The undesired signal is often referred to as noise. The ratio of the magnitude of the signal to that of the noise is important as an indication of possible error limits and detectability limit. The frequency range of signals that can be utilized by an instrument system determines the amount of useful measurement data that can be handled per unit of time. The fundamental definitions of information, frequency, bandwidth, noise, channel capacity, and their interrelations are all involved in information theory; thus this field is clearly of basic importance to instrumentation, and particularly to communication instruments and systems. See INFORMATION THEORY.

Human engineering. This is frequently involved in instrumentation. To be operated by or to provide information to an observer, instrumentation systems should be designed to take account of his physical, physiological, and psychological characteristics. In design of dial displays or manipulative elements, visual acuity and body characteristics must be considered. In analysis or design of systems in which a human being provides a link between measurement and control, the reaction time and decision capabilities of the human being and his susceptibility to fatigue and to environmental factors must also be taken into account. See HUMAN ENGINEERING.

Cybernetics. Cybernetics relates to the field of man-machine communication and the application of information theory to response and automatic control in physiological systems. It is thus another field which partly includes and is partly included in the field of instrumentation. See CYBERNETICS.

Automation. This recently introduced term still has various meanings but generally implies the application of automatic control to an operation or process. As a term applied to economics and technology, it implies the modernization of industrial operations to utilize mechanized equipment and instruments for automatic control, measurement, and data handling to a greater degree. See AUTOMATION.

Trends in instrumentation. All ... and technology ... ing ...

f r example the expl rat of space ge erati n of power by nuclea react r and det rmination f high temperature propertie of mate ials pre se t new in trumentat on probl ms In general n strumentation res ar h eeks to attam higher accu raci s, greater en ti t es capability of measuring xtreme values appli abil ty u d r extreme condi ti n of use and capab l ty of resol ing changes or eff cts that ecur at extremely h gl pe ds h as nucl a phenom na See PHYSICAL MEASUREMENT

The tre d t wider u e of nstrumentation fo tom tic mea rem nt and ntrol i dustry is co tinually accel rating and whole new ndustri s a e eme ging wh ch c uld n t ex st w thout highly soph t c ted in trum ntati n This trend will con t u at a rate l m ted only by qu t ons of c t saf ty and rel bility Reli bility parti larly of ele t o c c mpo ent ha b n a seri us problem but w ll mprove a a result f d elopments in solid t t e cu t el me t n w mat ials new tech qu s and mo e atte t on to o er all system eng n r ng S RELIABILITY OF EQUIPMENT

An tl ig ificant trend is th nc a ing ut li zat n of data proce ing devi s, r corde s om p t s and m lar eq ipment for aut m t c orting sto g and r p d sele ti e retr e al of inform t on d nume al d ta i bank g a counting d doc m ntat on S mila d c s are be ng ad pt d fo utomat c read g l d ng to automat c lan gu ge tran l t on

Comput r theo y s bei g xtended t the de gn of l g c ma h n s nd elf-o ga ing y tems whi h may sim late not only the pr ce s of re memb ng and rea o ng b t l the pr cess of lea n g Me xt n on of speed and cap c ty will oon mak fe bl th u f c mp te s to om pute weathe p edicti n from analy is of met o o- l gi l data f om a w ld w de bs rvat o n t w rk t analyze and fore a t co m c t end t se l g t r q ir m nts and m l t ry capab l t s nd t pred t th pr bable utcome of mil t ry nt r r politi al c t ts.

In the m di al fi ld tr m ntat on fo auto- m t t t of phy i log cal b l mical and e l g al pa met rs now b ly me g ng but s rtain t bec me widespr ad Correlatio d ices a e b g dev l ped f r d agn s and cl n i l i strume ts f locati n a d id ntifi at on of nternal ll r mult ply ng n number and p ec)

In ed ati a d o is l in trum nt a e being d eloped nt n i ly S ppl m nted by automatic te r ng dev es and oth t uments f r learn ng th y pr m great a th effic ncy f the h l edu at n l y t m [W A W]

Bibl g phy W C B l (ed) *Phy l M th d n Ch m I 4 ly* 1 1 1950 H Ch t n t a d R W May *S re me h i m d Regu l r Sy t m D gn* 19 1 D M Co id ne red) *P f i m nt a d C t ls H dbo k* 19 B C D lahooke *I d st ial C t l I st m t* 1956 C S D pe W McK y a d S Lees *Instrument Engineering* 3 ols 1952 D P Eck man *Industrial Instrum ntat on* 1950 E M Grabbe *Automation in Business and Industry* 195 E M Grabbe et al (eds) *Ha dbook of Automatio Computation and C ntrol* 3 vols 1958 I A Greenwood J V Holdam and D Mac Rae El ct onic *Instruments* ol 21 1948 F K Harris *Electri al Measureme ts* 1952 I F Kin nard *Applied Electrical Mea urements* 1956 Arthur D Little Inc *Elect oni Data I rocessi g Industry* 1956 G J Murphy *Basic Automatic Control Theory* 19 I M H Nichols and L L Rauch *Rad o Telemetry* 2d ed 1956 H C Rob ert *Mech n cal Meas rements by Electrical Meth ods* 2d d 1951 T N Whitehead *The Design and Use of Instruments and Accurate Mechanism* 19 4

Insulation electric

Mat l of h gh re isti ty u ed to confine the elec tron in a conduct r a it may g ide them to some u eful dev e Fo lect ic wiring the insulati n is limited to fa rly flexible types

INSULATION REQUIREMENTS

The appl cation f insulat ons are a ied that cho ce mu t be m de fter c n id r tion of the nece sary prope t e and the weaknes es of the in sulation and f th pec al c r um tance of in tall t on No in ul ti n has all the ad ant ge the i sulat n sho ld be o ch en that its d d an tag a e not a det iment i the specific appl ca tion

Many desi able haracteri tics are not perma nent. The efore the prope ties f the m terial alter a p riod of ye rs n the en iro mental condition m st al b kn wn New m te i l r q ire t me t de el p th r u fo e een weakn s es

Electrical requirements These vary with use sp ific prop rti s f interest depe d upon the p- pl at o The importa t p pert es of nsul tion are di u sed bri efly See DIELECTRICS

R st ity Commonly mea ed as n ul ti n re- s tanc th s i ba ed on a di ct cur nt measu ment f fl w into the in ulati n afte el ctrifi a t on of 1 m n The urrent hould l e small and the in lat n e st nce larg In itself it i not per h ps th mo t imp tant char ct rist c but deterio- r ti n s fi n f u d t occu f ter in low n la t on r sta e materials und r weathering co di ti ns It is a la ble measure f con i tency and uniform ty i manufactur If in rvice it should d op bruptly or fairly apidly a ervic f lure s l kely t f ll w

D el ctri st ngth Th s prop rty d term nes the abi l ty of the in ulatio to r si t pun tu e by elec t c potent als It ad er ly aff cted by weath r i g or gi g by high temper re by c nt nu d heat and by th ent anc of m i tu

Pow f to Th s i mea ur of the p wer l s t the insulat on and hould be l w A ap d n c e s a dang sign It i mport nt in h gh voltag ble b t um t t i low oltage ca ble xe pt th s used for c mmunicat n It

to initiate corrective action Since the output measurement is used to control the input such systems are called closed loop or feedback control systems For discussion of the use of instrumentation in control systems *see* CONTROL SYSTEMS SERVOMECHANISM

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Trends in instrumentation Advances in science and technology make ever increasing demands on instrumentation E y new of in tigati n

Som ch ract i tics of pl sti l s latio

Ch ra teri t c	P ly thyl ne	P ly tyren	Poly nyl hl rid	M;l	Nylo	Tefl n	Kel F
In ul t es ta ce	H gh	H gh	Can be anyt	Good	F ir	Good	Good
D lectri t e gth	Good	Good	Can be anything	Good	I	Good	Good
P w f ct	Low	Low	R the high	Low	H gh	Low	Low
D lectri consta	Low	Low	M d um	Low	Medi m	Medi m	Medium
Chem cal es ta ce	Good	Good	Good to f	Good	Good to fa r	Good	Good
W t r pe meab l ty	Good	Good	Good to f r	Good	Fa r	Good	Good
Re ta ce to nlight	Good if bl k	F ir	Can be good	Fa r to good	Good if bla k	Good	Good
Flamm ble	Yes	Yes	No	Yes	Yes	N	N
Ten l t gth	Good	Good	Good	H gh	Good	Good	Good
Resista ce to d f rm tio	Fair	Good	F	Good	Good	Good	Good
Abra easta e	Good	F to good	Good	Good	Good	Good	Good
St ff ess	Cons d bl	Extreme	Anything des red		Con d bl	Con ide abl	Con d ble
Cost	Low	Low	Low	R th r h gh	Fa	H gh	H gh

P ly yl hlo d Th s pla t c n w d u today It i d lt t g ral it p operti e and t a b my ded t mak a ngle pr pe ty x pt al The table h uld be i terp eted with th t l m t t in m d It d st n tly n it t t mp t r It n g f te tha y ly thyl e up t a point d b m ng h d r t low tempe t es It al bject to flow u d pres ur ev n t om t mp tu

Myl Th s ot n mu h use as an i ul ti n lth ugh t can be ed n th n t p f rm Se POLY ST R RESINS

Nyl n S m la t myla in m ny way nyl n is ul t d ng i ab a re t n but s n t u ed s abl ulati It u lly sed f r its phy i cal ben fit r th th n a an nsul t o Se POLY MOE RE I

T fl nd K l F These hl r e-fluor e om p u d h l m t d appl t n Th y a norm lly t ff d so m t be u d n thi la s Th y w th t d h gh temp atu (e 200 C) th n any th m fl x ble I t n S POLYFLUO OOLE FIN RE IN

Thermosetting materials M t als n th s l r n mally ft They can b t ded d r p s d th h at t ted u t l th longe ft h ool

Rubb mp d F l t n rubbe c m po nd a e h nged f om pl t c f rm t el t d t n l mb ti with lf r Th he t tr atm nt i lled l m g Nat al r bbe used l f q ntly f r m l t i recent y a th r m t l h bec m a lal l

Sy th t b (*Bu a S*) M m de a d a e f lly o tr lled y thet c ubb r la k the f gn m ti f t r l bbe nd s m u f rm Flect l l l t n a be m de w th ither n t ral or syntheti rubbe but the latter hould yield mo n form a d repr d c bl res lts

Rubbe comp u d can be m d w th good s lat n ista nd d elect i tr gth m d m pow r fa to nd S I C and w th res tance to chem c ls w athe ng, and mo t co d ti ns They a e mo fl xibl and are easi r to ha dle and in tall th n pla t c

Us ally they need p ot t n fr m mechan al ab s They hur a d ar u lly l m ted t a maxi m m te t oltag f 35 000 lt The g g f an h c mp und usuall au es them to harden but if u d st rbed th y nti ue to functio el c t e ll

Butyl Thi synth t rubb ha not be n u d t the h ghest oltages beca e it dielectric trength i l ss than th t f n S and f natural ubbe It w ll n t ha d n u der us oftens Ag n e rt i ch racteri ti s re a entu ted n some omp d rd not n ther o g n al zat n f haracte t s ca n t ccu at ly every c

Neop n Th s bb l k mat l com p ded t lo k l k a bbe mp und It does n t ha e th ele t ical p pe t usu lly equ ed a d ed princ p lly f tl e m h n al p te t f s lat n wh h t e l es S h neop m e sh ng i ta They e t th t of th su d o l H w v r l nd w t r c n p trate th m

Sil c ubbe Th s a e pen e m t rial b t t t d ged by temp at f m 150 t 00 C It l t c l p p rt a good It u ally phy ic lly we k, alth gh thi n b im pro ed m v et s S RUBBER SILICONE RESI S

usually increases with rise in temperature of the insulation

Dielectric constant Also known as S I C (specific inductive capacity) this is a measure of the charge required to bring the apparatus up to voltage compared to that required if air were substituted for the insulation It is principally of importance in communication circuits and low values are preferred except for capacitors where high dielectric constants provide high energy storage in a small volume *See* DIELECTRIC CONSTANT

Temperature requirements These vary with each application and installation A compromise is usually necessary because an insulation good for high temperatures has other shortcomings and the same for low temperatures The Electrical Code and American Institute of Electrical Engineers Standards give limiting temperatures at which specific insulations shall be u ed This means the final temperature of the insulation which is the result of the temperature of the surrounding medium usually air and the heat from the current in the cable conductor Temperature should be maintained at a value at which the insulation will last for a long time Most insulations are stiffer and more likely to crack on bending at lower temperatures and conversely to soften at higher temperatures This applies to temperatures applied for short duration Higher temperatures applied for long duration usually harden and possibly embrittle insulation although some new rubber compounds soften and become puttylike In both cases the value of the insulation is impaired and electrical failure may occur if bent in the first case or due to its own weight in the latter case

Where a nonflammable cable is required some other desirable property must usually be sacrificed

Mechanical requirements Normally electric insulation should be designed to hold electricity not to withstand mechanical abuse For the necessary rough treatment that may occur in installation of cable braids tapes or sheaths are employed over the insulation as a protection These can be designed to withstand the mechanical treatment likely to occur and the insulation can be designed for optimum electrical functions Of course the insulation should not break at the low temperatures anticipated or soften at the high ones Some materials will even flow at temperatures not usually considered high these are unreliable as insulation

Chemical requirements These are usually determined by the specific application intended for the wire Sometimes resi tance to oil or liquids gas fume or airborne powders in chemical plants is required It is usually the mechanical protection of the insulation that must be designed to withstand this environment rather than the insulati n and each case need *special consideration*

Chemicals in the soil around buried cables or in ducts and manholes around duct cables can cause *deterioration* This again usually occurs on the mechanical protection of the cable but may apply to the insulation itself About the only guide for choice is to use an insulation that has proven by many years of service its suitability for uch conditions

Water can have disastrous effects if it enters the insulating medium of a cable This is e pecially true with paper insulation either dry or oiled or with varnished cambric Some compounds of rubber can hold appreciable amounts of water without harm to their electrical properties but others are seriously affected In many cases water absorption as a criterion of serviceability of an in u lation is exaggerated and undue importance may be given to it Its importance actually depends on its effect on the life or the electrical properties needed for the specific application of the in ulating material

Many seemingly impervious materials have been used for keeping water and oil or hydrocarbons away from insulation with the later disco ery that these liquids can pass through the barrier without adversely affecting it It is thought electric potentials sometimes aid in the transfer and penetration by the liquid

FLEXIBLE INSULATION

Insulating materials are often only one ingredient in a compound finally applied to a wire as insulation An infinite variety of mixtures can re ult all based on the same primary ingredient which often gives its name to the cla s Still the properties of the compounds may be so different as not to de erve grouping as a certain cla Such compounding may make a poor material or an out tanding one both with the same major ingredient In general insulations are either thermopla tic or thermosetting In others the effect of heat has no function There are many insulating material only the more important are discussed here

Thermoplastic insulation Materials in this cla s can be softened by heating they can be extr ided and when cool return to their original conditi n The general characteristics of the e material are compared in the table

Polyethylene This is particularly important for high frequency applications however it ha short comings It melts at about 110 C so that sl ort circuits or o erloads of current on a cable may cau e the insulation to run off It is very stiff and in thick walls on wire may pr e too stiff for u eful ness Cases of cracking have occurred in ervice mo tly due to certain g ea es or hydrocarbon Newer higher molecular weight p lyethylene is designed to avoid this but may lo e ome of tl e ad vantage f the original polyetl yle e *See* POLYOLEFIN RESINS

Polystyrene This al o ha ex eptional electrical propertie but it must be u ed in thin film or where it will not be l ent l e a se thick walls are tiff and l rittle Its electrical properties are le s affected by change of temperature than most in sulat ons *See* POLYVINYL RESINS

ith tand b nd ng during ma factu e but nly ba t th t nd low oltage It i u ually appl ed i th f rm f enam l or cott n e i g but f r larg machines th trand m y be wrapped with glas fiber l est r m ca pap r tap r with paper in th o of il filled t ansformer The turn in ulation i form d by wrappi g the conduc to s w th tape or by nterp ing pa ato s of he t mate i l The n ulat on to gr d m y be f rm d of r g d p ols n wh ch th coils are wou d fo mall tr n f rm s and fi ld l or m y e n t f lot l ners made of Myl r r ll l e a etate film pap r m ca r gl cl th r a comb n t n f th n in mall r tatin machines For l rge r t ting ma hin th ils r wr pped w th fl x bl h et t p d e tho oughly im p egn ted w th in l t g arn h The c ls may b molded the i a press or by mm r n i a l q d u der he t d pre sure The n ulati n is appl ed in erl pping l y rs d pp d i arn h nd b ked t make th u fa e c eep ge paths l ng a d t seal the i t r ti es

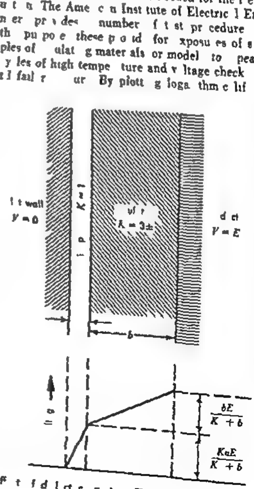
R g d n l t n sy t m ha an alm t nfi t riety f p bl f rm dep ndi g o the siz typ t te d d e a d e i o m nt of the equ p m nt Any o pec f pp atus m y e s ty f m t rials i many d ff nt fo m s om pon nt f it s l ti n s t m After ele t n tl m t table nd ompat ble mate al the de gne mu t pro d f r th appl cat n nd as embly s h w ys th t the mpl t d t uct e w ll ha e ad quate d le t i tr gth both i t ally nd n a l g t me ba nd w ll w th ta d ll th overs lt g m han l t e e temp a tu e a d r m ntal e p u s th t m y o ur in s rv c

Voltage requirements U ally cl d on d t r rgid in l t n y te r eq i ed to w thst nd i ti lly a te t oltag f twee the up ply olt ge pl 1000 lt Add t nal t t ch a r peated g impul lt g s may be e qu red t heck the tr nd and t rn i ul t n A h l p bl m i m et ng th e r qu r m nt s t th t th ltag d tr b ti al ng the w nd ng d n s h th kn s f nsul t o does t n t essa y p rt

A i d ted th f g r th d l ctr c t e al ng a y path made n f d ff ent mate i l n se es i n ersely pr p rt al t th r al e of th d l t n t nt K K i lly 3-6 f r gid n ul t nd l f a r so that a th n laye f ai betw the i ulati n and a el t w ll may h ve t s th ee mo e tim th t n the insul t n itself Beca a bre k d wn at b t 80 lt / mil lect d h rg o c r a may be xp ted h e th l t n st e e ceeds about 30 k th l t port n f h gh olt g l e g n m du t g ating which h t r t th e t m l pa nd r al m de f o es t tmat al ch a m e

Temperature requirements Org n in l t ng m t al u d n h m l and phy i l ch nges when expo ed to high temperature The rates of m l ch m c l reactions such as oxidation of cellu lo e d ubl and th refore the sefu l l fe of mo t in ulatio systems is rou hly hal ed f r each 10 C increa e in temperatu e Insulating materials are grouped in tempe ature Cla s O A B F and H w th ominal contin ou temperature lim t of 90 105 130 155 and 180 C, e pect vely Varni h treated c tton pape amel and mo t org n c mater als are i cluded i Cla s A whereas gl s fib r and built p mica with a mall p oportion of o gan c materi l are in Cl B S me f the be t org c film mate i l have been h wn by te t to b uit ble for Cla B t mp ratures al S licone ompo nd il c ne treated Clas H material a d fluoroc rbo such as Teflon a e in Cla s H The H rm l re i ti ity of u ual in ulating materials is drop of bout 200 C/(watt)(n) of he t flow a d allowan e mu t be made for the temperature d ffe enc ac the in ulation thi kness Th tand rd perm t de iati ns from the nomin l tem per ture l mits depe ding on the s ze and type of quipment and the i t nded serv e

Insulation tests Servic xperience is requ red to pro e th t n in ul tion sy tem is fully satisfac t ry b t l fe te ts on materials and n complete sy tems will sh ten the t me needed for the r eval u t n The Ame c n Inst tute of Electric l Eng n er pr i des number f t st pr cedure for th pu po e these p o id for xposu es of s m ples of ulat g mater als or model to peated y les of high tempe ture and v ltage check un t l fail r ur By plott g loga thm c lif s



Eff t f d l ct c n t t K lt g d t but b tw d ct rs d l t w ll

Epoxy resins These are used as insulation of joints A liquid and a powder are mixed and heat is given off The chemical action sets it to a solid which is not flexible but has good electrical and mechanical properties

Heat insensitive insulations The effect of heat has no function in establishing the properties of the insulating materials in this group

Paper Paper insulation in multilayers oil impregnated and protected from moisture by a lead sheath is an old standby It is popularly used at voltages over 15 000 volts It has good electrical characteristics which change with age Its weakness is the lead or similar sheath which must be in perfect condition to keep the cable dry and operating Lead is subject to crystallization and electrolysis which can perforate it

Varnished cambric This is a series of thin layers of varnished cloth Its electrical properties are not as good as paper oil cable and it requires the same moisture and mechanical protection usually a lead sheath It is used at lower voltages

Nitrogen gas This is used to a considerable extent as an insulation for high voltage applications It is used under pressure in a pipe containing the conductor

Magnesium oxide This is a novel insulation for low voltages but rather high temperatures It is enclosed in a copper tube and carries the conductor at its center It is good for wet and dry locations and in special applications it may be used to 250 C

Asbestos Besides its heat insulating properties asbestos is an electric insulator to some extent particularly if impregnated with some waxlike substance It usually requires a water impervious sheath and is used for relatively low voltages It is also used in combination with plastics or varnished cambric *See* ASBESTOS [A S D]

RIGID INSULATION

Besides their use as flexible coverings for wires and cables insulating materials are employed in molded or built up form as components of rigid structures This rigid insulation must provide mechanical strength and stability of form as well as a dielectric barrier Mica glass porcelain and the thermosetting resins are the principal rigid insulating materials but these may be used in combination with any of the flexible materials

Mica A mineral of finely laminated structure and easy cleavage mica flakes are flexible tough and highly resistant to heat Mica is most often employed in the form of splittings about 1 mil thick which may be snowed on to sheets of thin paper or glass fiber bonded with a suitable varnish and applied in multiple layers of tape Finely divided mica is used with epoxy or other resins to make a mica paper without separate backing Ground mica is used as a filler in molded insulation *See* MICA

Glass An amorphous material glass ordinarily consists of a mixture of silicates borates phosphates and other materials with silica SiO forming 50–90% of the total content It is employed in a great variety of compositions Blown and cast forms are used Glass yarn or cloth made of fibers 0 2–0 3 mil in diameter is also employed *See* GLASS AND GLASS PRODUCTS

Porcelain This is a hard brittle and impervious material made from feldspar quartz, clay and other minerals The materials are finely ground intimately mixed in a liquid state molded into the desired shape while plastic dipped in glaze and fired at a high temperature *See* PORCELAIN

Uses of rigid insulation Rigid electrical insulation is used for supporting conductors and spacing them apart in a gas or liquid environment where the air or other surrounding medium is relied upon to provide the needed dielectric strength except at the supports Here the chief requirements are high surface creepage resistance and high strength to withstand the imposed mechanical forces including the shocks from short circuit currents The insulation must be impervious to water so that it will retain its high electrical resistance when washed or exposed to the weather and for the higher voltages it must be able to withstand arc discharges over the surface

For the highest voltages as for power transmission lines the conductors are hung on strings of suspension insulators or supported on bushing These are made of glazed porcelain with a series of skirts to lengthen the creepage paths and provide maximum resistance to flash over For medium voltages the bushings may be made of glass or molded plastics

For low voltages as for industrial control equipment and household appliances and where many conductors need to be closely spaced thermo setting plastic compounds are used chosen for their structural rigidity high surface creepage resistance ease of manufacture and low cost Besides a wide variety of synthetic compounds such as phenolic melamine and polyester resins composite materials such as phenolic resin coated cotton or asbestos fabric and impregnated wood are used

When the conductor spacing is too small for reliance on the dielectric strength of the surrounding gas or liquid as in transformers and rotating machines the rigid insulation must form a sealed barrier of high dielectric strength over the entire conductor surface The requirements are especially severe for the slot embedded conductors of rotating machines where the insulation thickness must be held to a minimum and where part of the surface may be exposed to high velocity cooling air often containing fine particles of conducting material such as carbon dust

In general the windings of electric machines consist of stranded conductors arranged in series or parallel connected coils or both each with one or more turns Thus three principal kinds of insulation are required for apparatus windings for the strand for the turns and for the complete coil The strand insulation must be flexible enough to

re ch a val d term ned by radı tıon a d sol d cond ction A few m teri ls ha e such fin pores that at atmo pheric p e ure their d mens ons are mall r tha the me n fr e p th of a r Such ın ul to conduct ıtıe l th n th t f t ll aır [C.B BR]

B bl og phy H S Ca lslaw and J C Jaege *C duct o of He t ı Sol ds* 2d ed 1959 W H Ma Ad ms *H at Tra m ss* 3d ed 1954 J D V rschoor and P Greeble H at transfer by gas cond ctı n nd rad atı ın fib s ns lations *Tra ASME* 74(6) 961 968 1952 G B Wilkes *Heat I sul t o* 1950

Insulation resistance testing

The test ng of the ele trı al e ı tance f d le t ı m te al n ı sul t r *Insul t n* res stance s m as ed ın megohms It o st of tw c nt but ıng fa to (1) the ol m res stance resultı g f om the e t ce to curre t flow thr ugh the l ume f the mat rial and (2) th surfa e res st an e du to the re tanc to current flow er the urface of th mat r al The e two resistances are elect ı ally n p rall l and ıt ı mp s ble t sep a ate th m a g) m a urem nt If b sıc ın l t g p opert s f a materı l ar be ng tud ed ıudı ı s h ı f mpl ı and el ct od c n fig t n an emph size ne ff t o r th other so that re able evaluatıng d ta of ch f ctor an be bt n d

If the nd t ons f m urement do n t p rmıt h co t l as the ch ckı g of ın ulat on res t nc f l rg g ne m w nd ng the t st ng dıt a d phy c l r g m nt must be evaluated r f llyı dete m n wh h, f either f ct ı d m a t and wh th r t the te t w ll p odu e the des r d l at of the wınd n Of ten only th t tal nsul t n res stanc ıs r quı ed nd ı d du l aluation of th f n nd l me ffect need ot be m d E pt fo the mplest f m u em nt uch th e tan of ea p t ı rmı l r th point to-p ınt ı tan e f a w t h th u f a g a d c t ıs s e t al fo p ec se and a rat e ıt

Th t ta alue f the pp rent la t n res ı nc r te t u rent ch ges w th t me d ı th m f th e pr ple compo nts (1) the ur nt r q ed t ch ge the pa t e f th nt ct g elect od (th s usually e mpl t d ı m o r mıll ec nd les th cap ıtan e nd t rnal ı ı a e both l rge) (2) the rrent du t d lect absorpt (y la t m tes day) d fin lly (3) th c n l ctıo c t h h ı d t tr ath r than appa nt ın lat t

Bec u f th d tı at ecessary t p e fy f ll ll t t nd t of test volt g t m f re ı n rr nt m u me t afte applıc tıo f lt g t mpe t h m d ty l t ry p t test nd th t ı f apa t n e ha g Al o ıf th mpl m t be g u ded ıt m y be neces- r t se a h ghly l ted po s pply S

Dielectrics Insulator electric Resistance electrical Resistivity electrical

Guarded deflection method This method for measurıng ınsulat n resıstance ıllustrated by Fig 1 uses the ltmeter ammeter method (*see* Resistance measurement) The voltage ıs mea ured with a voltmeter of su table range the current ı meas ured by a calıbr ted gal anometer with an Ayrton sl unt for r nge exten ıon or a vacu m tube dc am pl fier calibrated as a m cromıcroammeter with ap- propr te mult plıers

A mod f catıon of thıs method whıch perm ts tl e *compar so of a high re ı tance standard with th ı sulatı n re stance under test* ıs shown ın Fıg *1b* In th s meth d neıther the test volt g nor the curr nts need be kn wn since the te t resı tance ıs propo tıonal to tl e omparıson tanda d and the rat o of two currents

In ea h of the e ı r uıts the *requı ıte guarding* of the te t equ pme t ıs shown by dotted line with the guard f the ample c nnected to the equıp- ment guard It s e sential that all of tl e qu p- m nt hown wıth the gu rd line be mounted on th gua d plate or cı cuıt H wever the ınsulatıon requ rem nts betwee gua d and me surıng cırcuıt are not severe Thı ın ulatıon shunts the ı ternal re st nce of th measurıng c rcuıt nd ther f re need o ly b 10-100 t mes thıs alue t mınımı e the error f om th s sou ce If an ele tron c mıcro- mı roammeter ı u ed ıt cırcuıts ıncludıng such

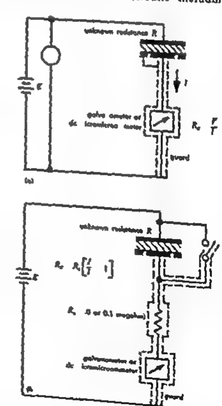


Fıg 1 Cı c t f g d d d fle t me m t of f ı ı c ( ) Voltmet -amm t m thod (b) C mp o m thod

absolute temperature on an inverse scale and extrapolating back to the proposed operating temperature the life expectancies of alternative materials and systems may be compared

[P L A]

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Insulation heat

Materials whose principal purpose is to retard the flow of heat Thermal or heat insulation materials may be divided into two classes bulk insulations and reflective insulations The class and the material within a class to be used for a given application depend upon such factors as temperature of operation ambient conditions mechanical strength requirements and economics

Examples of bulk insulation include mineral wool vegetable fibers 85% magnesia calcium silicate with asbestos vermiculite silica aerogel diatomite and insulating fire brick They retard the flow of heat breaking up the heat flow path by the interposition of many air spaces and in most cases by their opacity to radiant heat

Reflective insulations are usually aluminum foil or sheets although occasionally a coated steel sheet an aluminumized paper or even gold or silver surfaces are used Their effectiveness is due to their low emissivity (high reflectivity) of heat radiation

Thermal insulations are regularly used at temperatures ranging from a few degrees above absolute zero as in the storage of liquid hydrogen and helium to 3000 F in high temperature furnaces Temperatures of 4000–5000 F are encountered in the hotter portions of missiles and rockets the temperature exposure lasting only minutes or seconds so that insulations that would be destroyed by protracted exposure to these temperatures are successfully used

Heat flow The distinguishing property of bulk thermal insulation is low thermal conductivity Under conditions of steady state heat flow the following empirical equation describes the heat flow through a material

$$\frac{q}{A} = k\frac{A(\theta_2 - \theta_1)}{l}$$

where q = time rate of heat flow A = area θ_2 = temperature of colder side θ_1 = temperature of warmer side l = thickness or length of heat flow path and k = thermal conductivity representative values being listed in the table For a given thickness of material exposed to a given temperature

Thermal conductivities of selected solids

Material	Density lb/ft	Temp F	Conductivity k† Btu/( )(h) (ft)(F)
Asbestos cement board	120	75	4
Cotton fiber	0 8 0	75	0 6
Mineral wool fibrous rock slag or glass	1 5–4 0	75	0 27
Insulating board wood or cane fiber	15	75	0 3
Foamed plastics	1 6	[illegible]	0 9
Glass			3 6– 3
Hardwoods typical	45	75	1 10
Softwoods, typical	3	75	0 80
Cellular glass	9	75	0 40
Frozen sand (4% moisture content)	100	40	4 5
Silty clay loam (0% moisture content)	100	40	9 5
Gypsum or plaster board	50	75	1 1

From American Society of Heating Refrigerating and Air Conditioning Engineers, *Heating Ventilating and Air Conditioning Guide* 19 9

† Typical values not to be used for design calculations

difference the rate of heat flow per unit area is directly proportional to the thermal conductivity of the material

In the unsteady state or transient heat flow the density and specific heat of a material have a strong influence upon the rate of heat flow In such cases thermal diffusivity $\alpha = k/\rho C_p$ is the important property Here ρ = density and C_p = specific heat at constant pressure In the simple case of one dimensional heat flow through a homogeneous material the governing equation is

$$\frac{d\theta}{dt} = \alpha \frac{d^2\theta}{dx^2}\bigg|_0^l$$

where t = time and x is measured along the heat flow path from 0 to l

Thermal conductivity In general thermal conductivity is not a constant for the material but varies with temperature For metals and other crystalline materials conductivity decreases with increasing temperature for glasses and other amorphous material conductivity increases with temperature Bulk insulation materials in general behave like amorphous materials and have a positive temperature coefficient of conductivity

Thermal conductivity of bulk insulation depends upon the nature of the gas in the pores The conductivities of two insulations identical except for the gases filling the pore spaces will differ by an amount close to the difference in the conductivities of the two gases

Increasing the pressure of the gas in the pores of a bulk insulation has little effect on the conductivity even with pressures of several atmospheres Decreasing the pressure has little effect until the mean free path of the gas is in the order of magnitude of the dimensions of the pores Below this pressure the conductivity decreases rapidly until it

s a d t define an i tegral t an form Mo e ge rally the int g al may be a m ltipl integral and th fun t J G ϕ may d pend on larger num be of var bles Equati (1) tl ght of a tran f rm g whol cla r pace of funct on $\phi(y)$ t an ther cla of fu ct on $f(x)$ The fun ti n $G(x\,y)$ is the kern l of the tra f rm On of the imp rtant u e f such a tran fo m i ba ed n the f ct that a pr bl m p d in one of the tw pa e i q t n may h mo e ea ily ol ed in the other F r e ampl a diff re tial qu ati n to be l ed fo th f n ti n $\phi(y)$ ma b c me an alg br c quat on f r the unknown f ct on $f(\ )$ S e LAPLACE TRA SFORM

The two b e problems fo any integral t ansform a e in e s on and repr entation I in e s n the aim s to rec e $\phi(y)$ fr m $f(x)$ the ke n l $G(x\ )$ being kr wn Th t Eq (1) i tho ght of an i tegral equ t n (of th fir t k nd) t be l ed f the nk own f n tion $\phi(y)$ A me s f alculating $\phi(y)$ fr m $f(x)$ call d an i n f rm l and in its pr n the t ans f m chiev s m m m utility i c xpl cit p s age f m ea h pac to the the thus s ed In ep tatio the qu st n i wh ch f t ns $f(x)$ m y b writt n r ep e ted in the f rm (1) Th t is one a k wh ch f n t ns $f(\ )$ w ll m ke Eq (1) l ble f r $\phi(y)$ U n lly th s p blem becomes more t a tabl when th solut $\phi(y)$ a e r t cted to s m sub pa e uch a th f of p t r bound d fun ti

Inversion theory In ma y ca es wh e th n p blem h been olv d n ve operat h s d fferent al tegral per to ha been f u d d pending p h p n pa am t r wh h a mpl h tl i e at n It may b d t d by $O\{f(\ )\}$ Th me s that fo each al f th p am ter t me per ti n O on $f(x)$ d f ed F example, t might be 3 d th ope at m ght t of c mp t ng the th d de i a t of $f(\ )$ S ppo e that O appl ed t Eq (1) prod c

$$O\{f(\ )\} = \int_{-\infty}^{\infty} G(\ \ y)\phi(y)\,dy \qquad (2)$$

wh $G(\ \ y)$ s a ew kernel f ch t In fa r able a th nteg l (2) ppr hes $\phi(\ )$ a t pp a he a t ble l m t fo xample when G pp a hes th Di a fun t n $\delta(x-y)$

An import t pec l a e of Eq (1) th n l t n tr f rm wh th kern l is fu c t $f(\ -y)$

$$f(\ ) = \int_{-\infty}^{\infty} G(\ -y)\phi(y)\,dy \qquad (3)$$

A q al nt f m of Eq (3) i

$$F(\ ) = \int^{\infty} K(xy)\Phi(y)\,dy \qquad (4)$$

th h g f i ble e $y = e^{\ }$ c rr e Eq (4) t i Eq (3) fte itable h ng in t t

Transformation formulas Many f th l l tr f rm ha be n n med f r the r gi al principal inve t gat r A few of the more important one can be listed with the names rd narily at tached t them

For Eq (1)

A Blater l Laplace	$G(x\,y) = e^{-xy}$	
B Fou i r	$G(\ \ y) = e^{\ xy}$	
C. Mell n	$G(x\,y) = y^{x-1}$	$y > 0$
	$= 0$	$y < 0$
D Stieltjes	$G(x\,y) = (x+y)^{-1}$	$y > 0$
	$= 0$	$y < 0$

For Eq (3)

E. D chlet	$G(x) = x^{-}\ \sin x$	
F Fej r	$G(\ ) = x^{-2}(\ \text{in}\ x)^2$	
G F actional (Weyl form)	$G(\ ) = (-x)^{\mu-1}$	$x < 0$
	$= 0$	$x > 0$
H Hilbert	$G(x) = x^{-1}$	
I P ard	$G(x) = e^{-\|\ \|}$	
J Po sson	$G(x) = (1+x^2)^{-1}$	
K. Laplace (un lat ral)	$G(\ ) = e^x e^{-e^x}$	
L. St eltjes	$G(x) = \text{s}\ \text{ch}\ (x/2)$	
M We erstra s o Gauss	$G(\ ) = e^{-x}$	

For Eq (4)

N Fou i cos ne	$K(x) = \cos x$
O Four sine	$K(\ ) = \ \text{in}\ x$
P Hankel	$K(x) = \sqrt{x}J\ (x)$
Q Laplace (u ilateral)	$K(x) = e^{-}$
R Me j r	$K(x) = \sqrt{x}K\ (x)$

He e $J\ (x)$ i a Be el fun t on and $K\ (x)$ a modified Bes l funct o Certain t ansform re l sted tw e be au of the r f e ju nt appearance in two eq i le t forms In fact all of the abo e are con lution t an f rm cept A B and C. It c n b en al o that A a d C are the same t ansf rm (et $y =$ in C)

Representation Th i r on theory for a l rge cla s f on olut on tran f rm h s b en com pl ted Ope at on l c l ulus a gu d to the m thod (se OPERATOR THEORY) If the symb l D st nd f r d ffe ent ati w th respect to x l ut i n theless tr ated a a numbe in the famili rie

$$e^{tD} = \sum_{k=0}^{\infty} \frac{t^k}{k!} D^k$$

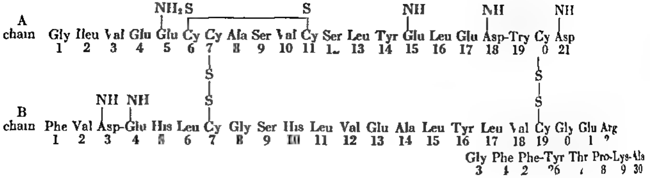
one i l d t make the d finition

$$e^{tD}f(x) = \sum_{k=0}^{\infty} \frac{t^k}{k} D^k f(x) = f(x+t) \qquad (5)$$

si e the s r s ( ) p e i ly the Maclaurin ex p n on of $f(x+t)$ if D^k i allowed t me n a kth ders ati e

N w c ns de the b l t al Lapl e t n fo m f $G(t)$ n Eq (1) den t g it by $1/E(\ )$

$$\frac{1}{E(\ )} = \int_{-\infty}^{\infty} e^{\ } G(t)\,d \qquad (6)$$



Structure of cattle insulin

1924 demonstrated that the anterior pituitary plays an important role in the etiology of the diabetic state of an organism See PANCREAS

The biological potency of insulin preparations is given in terms of an international unit (IU) defined as the hormonal activity of 0 125 mg of an international standard preparation It is generally assayed by injecting the hormone subcutaneously into fasting rabbits and then determining the rate and extent of the lowering of the blood sugar level Pure insulin possesses an activity equivalent to 24 IU per milligram Insulin loses its physiological activity when treated with alkali to pH 10 or with proteolytic enzymes like chymotrypsin

Insulin is a polypeptide with a molecular weight of approximately 6000 It is generally prepared from beef pancreas and this bovine insulin has been found to be composed of 254 atoms of carbon 377 atoms of hydrogen 65 atoms of nitrogen 75 atoms of oxygen and 6 atom of sulfur The insulin molecule contains 48 amino acids which make up two peptide chains (A chain and B chain) joined by sulfur atoms or —S—S bridges A complete description of the structure of bovine insulin was achieved by F Sanger and coworkers in 1954 The structural formula is depicted above where Gly is glycine Ileu isoleucine Val valine Glu glutamic acid Cy cystine Ala alanine Ser serine Leu leucine Tyr tyrosine Asp aspartic acid Try tryptophan Phe phenylalanine His histidine Thr threonine Pro proline Lys lysine Arg arginine

Insulin preparations from other species such as pig sheep horse and whale have also been examined by Sanger and coworkers and have been found to be similar in structure to the bovine insulin except for the amino acid sequence comprising positions 8 9 and 10 in the A chain of the molecule The biological potency of insulin has not been found to differ from species to species nor has it been possible to differentiate the various preparations immunologically [C H L]

Insulin shock

A treatment for schizophrenic psychosis introduced by Manfred Sakel in 1933 It is also known as coma treatment The patient receives a course of 20–50 treatments consisting of gradually increasing doses of insulin until coma is reached Patients are awakened by oral or intravenous applications of sugar or glucose See SCHIZOPHRENIA

The treatment is an empirical method not based on a satisfactory theory Reports about results of this treatment have always been contradictory ranging from enthusiastic reports of 80% recoveries to very conservative estimates in which the number of recovered patients hardly exceeds the rate of spontaneous remission Factors such as the general hospital atmosphere the attitude of the therapist and varying criteria of recovery explain such wide discrepancies

Administration of insulin coma treatment is a complex time and personnel consuming procedure For this reason and because fatalities have occurred and a number of patients have received lasting neurological damage insulin shock treatment has been on the decline It has been replaced largely by electric convulsive treatment and by drug therapy with tranquilizers and psychic energizers (see PSYCHIC ENERGIZER TRANQUILIZER)

In subcoma treatment the doses are kept small enough so that not coma but its prodroma such as sweating drowsiness and hunger are produced During this subcoma state the patient may be more amenable to psychotherapy See PSYCHOTHERAPY [F C R]

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Intaglio (gemology)

The name given to the type of carved gem stone in which the figure is engraved into the surface of the stone rather than left in relief by cutting away the background as in a cameo Intaglios are almost as old as recorded history for this type of carving was popular in ancient Egypt in the form of cylinders The cylinder as well as the more familiar form of intaglio was popular to impress seals on sealing wax Intaglios have been carved in a variety of gem materials including emerald crystalline quartz hematite and the various forms of chalcedony See CAMEO [R T L]

Integral transform

An integral relation between two classes of functions For example a relation such as

$$f(x) = \int_{-\infty}^{\infty} G(x\ y)\phi(y)\ dy \qquad (1)$$

i a d t d fin an *integral tra sform* More gen e lly the tegral may be a mult pl integ l and the fun t on f G ϕ may d p nd on a l rger num b r f ariabl Equat on (1) i thought f s tr form g a wh le la s or pac of functi n $\phi(y)$ nt a other cla s f f nct ns $f(x)$ The f n t n $G(x\,y)$ i th ke n l f the tr n f rm On of the importa t u e f s h a t ansf rm i ba ed on the f ct that a p oblem p sed ne of the two spa s in question may b m re a ly ol ed in the ther For xample, d ffe enti l qu tio to be olved f th f n t on $\phi(y)$ may become an lgebra qu t o fo the unknown functi n $f(x)$ See LAPLACE TRANSFORM

The t problem for any integral tr n f rm are t rsion d rep s ntat on In inv r s on the a m is to o er $\phi(y)$ fr m $f(x)$ the kernel $G(\ y)$ be k own Th t Eq (1) s th ght f s ntegr l qu t n (f the first k d) t b l ed for th nkn wn fun ti n $\phi(y)$ A mean f calc lat ng $\phi(y)$ f m $f(x)$ s called a in r i f rm l a d n t pre en e th tra s- f rm ach e es ma m m til ty *ce expl c t* pa age f m h space to the oth m th as- u ed In r p ese tat the q est n s which fu t $f(\ )$ may be written *r rep ented* in th f rm (1) Th t is one a k wh ch functi s $f(x)$ w ll m ke Eq (1) l able fo $\phi(y)$ Us ally thi probl m be mes m tractabl when the sol t $\phi(y)$ are r t cted to me ub pac e h as the cl f pos t r bounded f t n

Inversion theory In many c es whe the n p bl m h b e ol d an in r n p r t r s h as a diff r t al r t g al perator h s been fo d d p nding pe hap n a p am t h h a ompl h t s on It m y b d ted by $O\,[f(\ )]$ Th m ans th t for a h lu of th par met r t me pe at n O r $f(\ )$ d fined F r ex mpl t might b 3 and th oper at m ght t f c mp ti g the third d t t e [$f(\ )$ S ppose that O pplied to Eq (1) p od es

$$O\,[f(x)] = \int_{-\infty}^{\infty} G\,(x\,y)\phi(y)\,dy \qquad (2)$$

wh e $G(\ \ y)$ a ew kern l f each t In fa or ll ase the i tegr l (2) app oaches $\phi(x)$ as t pp oa hes u table l m t f e ampl wh C pproa hes the D c δ fu t o $\delta(\ -y)$

An mport t spec l ca e f Eq (1) the l t o t f rm wh the ke nel i a func t i (y)

$$f(x) = \int_{-\infty}^{\infty} C(\ -y)\phi(y)\,dy \qquad (3)$$

A ru l nt f m f Eq (3)

$$F(x) = \int^{\infty} K(xy)\Phi(y)\,dy \qquad (4)$$

th h g f a bl e y = c rries Eq (4) t Eq (3) aft a s t ble hange in n tai

Transformation formulas M ny f th cla al t n f rm h been amed for the ig nal or pr nc pal inve tig tor A few of the more important nes can be l ted with the names ordinarily at t hed to them

F r Eq (1)

A Bilater l Lapl c	$G(x\,y) = e^{-}$		
B Fou er	$G(\ \ y) = e$		
C Mellin	$G(x\,y) = y^{x-1}$	$y > 0$
	$= 0$	$y < 0$
D Stieltjes	$G(x\,y) = (x+y)^{-1}$	$y > 0$
	$= 0$	$y < 0$

For Eq (3)

E D r chlet	$G(x) = x^{-1}$ s n x	
F Fej r	$G(x) = \ ^{-2}(\sin x)^2$	
G F a t onal (Weyl form)	$G(x) = (-x)^{\mu-1}$	$x < 0$
	$= 0$	$x > 0$
H H lbert	$(\ ) = x^{-1}$	
I P card	$G(\ ) = e^{-\|\ \|}$	
J Po ss n	$G(x) = (1+x^2)^{-1}$	
K Lapl c (mulate al)	$G(x) = e^{x}e^{-e^{x}}$	
L St ltjes	$G(x) =$ sech $(x/2)$	
M We erstrass or G us	$G(x) = e^{-x^2}$	

For Eq (4)

N Four e c s ne	$K(x) = \cos x$
O F ur e s ne	$K(x) = \sin x$
P Hank l	$K(x) = \sqrt{x}J\ (x)$
Q Lapl ce (umulate al)	$K(x) = e^{-}$
R Meije	$K(x) = \sqrt{x}K\ (\ )$

H re $J\ (x)$ i a Be l funct on and $K\ (x)$ a mod fied Bes el fun t n Certain tran for ns are l st d tw e becau e f th r frequent ppear nce n two qu le t f rms In fact all of the bo e are o v lut on t an f ms except A and C It c n be s en l that A nd C re the s m transf rm (set $y = e^{\ t}$ n C)

Representation Th ve s on theory fo a l rge cl s of onvoluti tran forms has been com plet d Ope ati al al ul s is a g id to th meth d (se OPERATOR THEORY) If the ymbol D st d for differe tiat n w th respect to x but is n nethel s t eat d as a numb r in th familiar s r es

$$e^{tD} = \sum_{k}^{\infty} \frac{t^k}{k} D^k$$

n l d t mak the d fin tion

$$e^{\ D}f(x) = \sum_{k=0}^{\infty} \frac{t^k}{k!} D^k f(x) = f(x+t) \qquad (5)$$

i e the es (5) s p eci ely the M claurin ex pansio of $f(x+t)$ f D^k i llowed t me a kth d r vat

N w con d r th b lateral Lapl ce transf rm of $G(t)$ n Eq (1) den t g t by $1/E(\ )$

$$\frac{1}{E(s)} = \int_{-\infty}^{\infty} e^{-\ } C(t)\,dt \qquad (6)$$

Replacing s by D and using Eq (5) one has

$$\begin{aligned}\frac{1}{E(D)}\phi(x) &= \int_{-\infty}^{\infty} e^{-tD}\phi(x)G(t)\,dt\\ &= \int_{-\infty}^{\infty} \phi(x-t)G(t)\,dt\\ &= \int_{-\infty}^{\infty} G(x-y)\phi(y)\,dy\\ &= f(x) \qquad x-t=y \qquad (7)\end{aligned}$$

If $E(D)$ were a number one could solve Eq (7) to obtain

$$\phi(x) = E(D)f(x) \qquad (8)$$

Finally reverting to the original meaning of D as a derivative one has in Eq (8) an inversion of Eq (1) by means of a differential operator $E(D)$

This argument is meant to be exploratory only but the result is accurate for a large class of kernels G and their corresponding inversion functions E In summary the inversion function is the reciprocal of the bilateral Laplace transform of the kernel It has been shown that the result is correct if for example $E(s)$ is the infinite product

$$E(s) = e^{b} - \prod_{k=1}^{\infty}\left(1-\frac{s}{a_k}\right)e^{\,/\,k} \qquad (9)$$

where $c \geqq 0$ and the series of real constants

$$\sum_{k=1}^{\infty} a_k^{-2}$$

converges

For example if $K(x) = e$ then Eq (4) is the Laplace transform Expressed as a convolution transform as in Eq (3) it becomes

$$e\,F(e\,) = \int_{-\infty}^{\infty} G(x-y)\Phi(e^{-y})\,dy$$

where G is given in the above list as entry K The bilateral Laplace transform of this kernel is the familiar gamma function

$$\Gamma(1-s) = \int_{-\infty}^{\infty} e^{-\,t}G(t)\,dt = \int_{0}^{\infty} e^{-t}t^{-}\,dt$$

whose reciprocal has a well known expansion in the form of Eq (9)

$$E(s) = \frac{1}{\Gamma(1-s)} = e^{-\gamma}\prod_{k=1}^{\infty}\left(1-\frac{s}{k}\right)e^{\,/k}$$

Here γ is Euler s constant In the present example Eq (8) becomes

$$e^{-\gamma D}\prod_{k=1}^{\infty}\left(1-\frac{D}{k}\right)e^{D/k}e\,F(e^{x}) = \Phi(e^{-}\,)$$

or if $e \;= t$

$$\lim_{k\to\infty}\frac{(-1)^k}{k!}F^{(k)}\left(\frac{k}{t}\right)\left(\frac{k}{t}\right)^{k+1} = \Phi(t)$$

This familiar inversion formula also serves to illustrate the operator O_t appearing in Eq (2) In the present case the operator is a differential one and the parameter t is an integer k which tend to ∞ See CONFORMAL MAPPING INTEGRATION

[D V W]

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Integration

An operation of the infinitesimal calculus which has two aspects The roots of one go back to antiquity for Archimedes and other Greek mathematicians used the method of exhaustion to compute areas and volumes A simple example of this is the approximation to the area of a circle obtained by inscribing a regular polygon of known area and then repeatedly doubling the number of sides The areas of the successive polygons are computable with the help of elementary geometry The limit of the sequence of these areas gives the area of the circle The area of each polygon can be regarded as made up of the sum of the areas of triangles with vertices at the center of the circle and so the process described is a constructive definition of an integral which is the limit of a sum Modern definitions of integrals as limits of sums are discussed in this article

The other aspect of integration is the process of finding antiderivatives that is for a given function $f(x)$ to find another function $g(x)$ whose derivative is $f(x)$ This aspect is related to the first by the fundamental theorem of integral calculus so both processes are called integration

Sir Isaac Newton emphasized the antiderivative aspect of integration and his work shows how much can be done in the applications of integral calculus without introducing limits of sums However limits of sums lead to very fruitful theoretical developments in the theory of integration as in the notion of multiple integrals for example and hence lead to a wider variety of applications Leibnitz the seventeenth century mathematician inspired the development in this direction but many years elapsed before the theory was given a firm logical foundation In the early nineteenth century A L Cauchy gave a clear cut definition of the definite integral for continuous functions and a proof of its existence Later G F B Riemann discussed the integral for discontinuous functions and gave a necessary and sufficient condition for its existence Thus the most generally used definition of the integral as the limit of a sum has come to be called the Riemann integral

Riemann integral The precise definition f the Riemann integral f r a real function f of one real variable x on a finite interval $a \leqq x \leqq b$ may be formulated as follows Let P be a partition of the interval $[a\ b]$ into n subintervals by points t where $t_{\ 1} < t_i\, t_0 = a\ \ t \;= b$ and consider a sum S of the form

$$S = \sum_{i=1} f(x\,)(t\; - t_{-1}) \qquad (1)$$

where $t_{i\ 1} \leqq x_i \leqq t_i$ The sum S depends not only on

the p rtit n P but on the cho ce of the intermed te po nts x It may happen that th um S app oaches a defin te l mit I wh n the maximum f the numb rs $(t - t \ )$ te ds to z r nd in thi a e I is alled th R emann i tegral (or the defi te i tegral) f f f m a t b a d s denoted by the Le bn tzian ymbol

$$\int^b f(x)\, dx$$

Al o f s s id t be integrable on $[a\, b]$ When f is a o t o fu ti n w th posit e value on the nterv l $[a\, b]$ the int gr l h s a mple ge m tr l nte pr tat o as the a ea bounded by the x a the ord n t s $x = a$ nd $x = b$ and th gr ph of $y = f(x)$ (F g 1) It s con ni t to define

$$\int_b f(\ )\, dx = -\int^b f(x)\, dx$$

F r funct f and g which a e ntegrable on $[\ b]$ th i t gral has th f ll wi g pr p rti s

(i) f i nt g able n e ry sub nterval f $[\ b]$

(i) For very tr ple of po nt d and in $[a\, b]$

$$\int^d f(x)\, dx + \int f(x)\, dx = \int f(x)\, dx$$

( ) $f(x) + g(\ )$ integr bl and

$$\int \{f(\ ) + g(\ )\}\, d = \int^b f(x)\, d + \int^b g(x)\, dx$$

( ) $f(\ )g(x)$ i integr bl and in part cul r $f(x)$ t g bl for ev ry re l n mber c and

$$\int cf(x)\, d = \int f(x)\, dx$$

( ) If $f(x) \leq g(x)$ on $[a\, b]$ th

$$\int^b f(\ )\, dx \leq \int^b g(\ )\, d$$

( ) $|f(x)|$ s tegrabl a d

$$\left|\int f(x)\, dx\right| \leq \int |f(\ )|\, dx$$

It c n be pr ed that f n ti n f i t gr ble n $[\ b]$ f d i if the tw c nd t ns f llow ng ar t fied f i bo nded o $[\ b]$ nd th t of po nt wh f i d c t u s ca b n lo d in es (po t f fi te) f tervals th m f hose l ngth arb t a ly e t ze

Ant derivati es T dev l p the fu dame tal theorem f t g l c l l t u be a n bl in

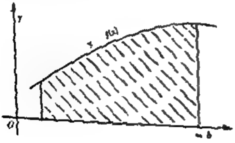


Fig 1

the interval $[a\, b]$ on which f is i tegrable then

$$\int f(\ )\, dx$$

is a function wh ch may be denoted by $I(u)$ If f is continu us o $[a\, b]$ then f is i tegrable and it is al o true that $I(u)$ has a deriv t ve $I'(u) = f(u)$ Now l t h be any antid r vati e of f that is $h'(u) = f(\ )$ on $[a\, b]$ Then $I'(u) - h'(u) = 0$ so $I(u) - h(u) =$ constant $= -h(a)$ by the the rem of the mean for derivativ s and the fact that $I(a) = 0$ s

$$I = I(b) = h(b) - h(a)$$

Th s is the f nd m nt l theorem of integral c l u lus and it how th t *definit integrals may be cal c lated by the proce s of find ng antide i atives* F r th r s on *ant deri ati es a e l equ ntly* called *ndef n te int al* and denoted by $\int f(x)\, dx$ and pe i l methods f f d ng indefin te integr l f r f equ ntly o cur ing functi n ccupy a la part f el m tary alculu Th pri cipal meth d are uth ed in the next s ct on The standard n ta t o f an i defi te ntegral of $f(x)$ s

$$\int f(x)\, dx$$

Elementary methods of integration Ob iously ach formula f r d ff r nt at on yi ld formula for definite i tegrat n

Method of s b tit ti F om the e i d fin te nteg al add t n f f rm fa can be obtained by the m thod of ub t tut n which is ba ed on the ch n ule f r differe ti ti g c mp s te f nct ons F ex mple fr m the fo mul

$$\int x^m\, d = \frac{x^{m+}}{m+1}$$

n obta ns

$$\int (\ ^2 + x^2)^m\ d = \frac{(a^2 + x^2)^{m+1}}{2(m+1)}$$

by th subst tut on $v = a + \ $ and

$$\int \ n^m x \cos x\, d = \frac{\sin^{m+1} x}{m+1}$$

by the s bst t t n $v = \sin x$

M thod f pa tial f tions In c e $f(x)$ is a q ot nt of two polynom l i x $f(x)$ may be repr ented a a m of a polyn mi l nd t rms of th f rm

$$\frac{1}{(ax+b)^m} \qquad a \neq 0 \tag{2}$$

$$\frac{A\ + B}{(cx^2 + d\ + e)^m} \qquad c \neq 0\ \ d^2 - 4ce < 0 \tag{3}$$

whe m a po ti e i teger and the coeffici nt a real This s alled th method of *part al f ac t ns* It a tu l e st o r qu r s a knowledge of the fact r f the denom nat r f $f(x)$ T rms of th form (2) ha e known indefin te int g al Term f the f rm (3) w th $m = 1$ c n al o b

integrated by elementary formulas When $m > 1$ a term of the form (3) can be written as a sum of terms of the form

$$\frac{\alpha}{(ax^2 + dx + e)^{m-1}}$$

and
$$\frac{(\beta x + \alpha)(2cx + d)}{(cx^2 + dx + e)^m} \tag{4}$$

By the process of integration by parts the indefinite integral of a term of the form (4) can be expressed in terms of the integral of a term such as (3) with m replaced by $m - 1$ Reduction formulas of this type are given in standard tables of integrals

A rational function of $\sin x$ and $\cos x$ may be integrated by the method just described after the substitution $u = \tan (x/2)$ has been applied This substitution reduces the problem to the integration of a rational function of u Various functions involving radicals can be integrated by means of trigonometric substitutions or by other substitution which reduce the problem to the integration of a rational function For example by setting $u = a + bx$ one finds

$$\int x^m(a + bx)^p\, dx = \int \left(\frac{u - a}{b}\right)^m u^p \frac{du}{b}$$

and when m is a nonnegative integer the right side may be multiplied out and integrated by the power formula even though p is a fraction

Integration by parts This is a very powerful and important method It follows from the formula for differentiating a product namely

$$d(fg) = f\,dg + g\,df$$

After the terms are rearranged and integrated

$$\int f\,dg = fg - \int g\,df$$
or
$$\int fg'\,dx = f(x)g(x) - \int gf'\,dx$$

where the arbitrary constant as usual has been omitted As an example consider

$$I = \int \frac{2x^2\,dx}{(x^2 + 1)^m}$$

which is a special case of (4) Let $f = x$ $g' = 2x/(x^2 + 1)^m$ Then $f' = 1$

$$g = \frac{1}{(1 - m)(x^2 + 1)^{m-1}}$$

so $I = \dfrac{x}{(1 - m)(x^2 + 1)^{m-1}} - \dfrac{1}{(1 - m)} \displaystyle\int \frac{dx}{(x^2 + 1)^{m-1}}$

The indefinite integrals of many of the commonly occurring functions are given in table of integrals in handbooks and textbook

The elementary functions are those expressible by means of a finite number of algebraic operations and trigonometric and exponential functions and their inverses The integrals of many elementary functions are known to be not elementary so they define new functions A number of these are sufficiently important so that their values have been tabulated Examples are

$$F(k, x) = \int_0 \frac{dx}{\sqrt{(1 - x^2)(1 - k^2x^2)}} \qquad (k^2 \neq 1)$$

$$\mathrm{Si}\, x = \int_0 \frac{\sin x\,dx}{x}$$

$F(k, x)$ is called an elliptic integral of the first kind The inverse of $u = F(k, x)$ is an elliptic function called the sine amplitude of u and denoted by x sn u (*see* ELLIPTIC FUNCTION AND INTEGRAL) Some of the nonelementary functions have been included in tables of integrals

Improper integrals This term is used to refer to an extension of the notion of definite integral to cases where the integrand is unbounded or the domain of integration is unbounded Consider first the case when $f(x)$ is integrable (in the sense defined above) and hence bounded on every interval $[a + \epsilon, b]$ for $\epsilon > 0$ but is unbounded on $[a, b]$ Then by definition

$$\int^b f(x)\,dx = \lim_{\to 0} \int_{+}^b f(x)\,dx$$

provided the limit on the right exists For example if $f(x) = x^{-2/3}$

$$\int_0^1 x^{-2/3}\,dx = \lim_{\to 0} \int^1 x^{-2/3}\,dx = \lim_{\epsilon\to 0} 3[1 - \epsilon^{1/3}] = 3$$

Similarly

$$\int_{-1}^0 x^{-2/3}\,dx = \lim_{\to 0} \int_{-1}^{-} x^{-2/3}\,dx$$
$$= \lim_{\epsilon\to 0} 3[(-\epsilon)^{1/3} + 1] = 3$$

When $f(x)$ is integrable on every finite subinterval of the real axis by definition

$$\int^{+\infty} f(x)\,dx = \lim_{b\to+\infty} \int^b f(x)\,dx$$

$$\int_{-\infty} f(x)\,dx = \lim_{b\to-\infty} \int_b f(x)\,dx$$

provided the limits on the right exist More general cases are treated by dividing the real axis into pieces each of which satisfies one of the conditions just specified For example

$$\int_{-\infty}^{+\infty} x^{-6/} dx = \lim_{\to-\infty} \int^{-1} x^{-6/3}\,dx$$
$$+ \lim_{\delta\to 0} \int_{1}^{-\delta} x^{-6/3}\,dx + \lim_{\to 0} \int^{1} x^{-6/3}\,dx$$
$$+ \lim_{b\to+\infty} \int_1^b x^{-6/3}\,dx \tag{5}$$

Because the second and third of the limits on the right do not exist

$$\int_{-\infty}^{+\infty} x^{-6/3}\,dx$$

does not exist However it is sometimes useful to as-

a valu t, alled the Cau hy pr nc pal value by r placi g th defi t on (5) by

$$\int_{-\infty}^{\infty} x \quad {}^{3} d_x = \lim_{\varepsilon\to 0}\left[\int_{1}^{-} x^{-/3}\,dx + \int^{1} x^{-4/3}\,dx\right]$$

$$+\lim_{b\to+\infty}\left[\int_{-b}^{1} - {}^{3}dx + \int^{b} x \quad {}^{/3}dx\right]$$

I th pa ti ula e the al i is ze

Th pre ed g defi ti ns apply to when th i t grand $f(\ )$ bou ded x pt i a b trarily mall ne ghbo hood of fin te s t f p ts I the l i g y s of the netee th ce tury a so t n w e m de to more g al ca e Then Hen l b gu p odu ed a e mp r t ely mple g ne l theory f r the a of ab l t ly n g nt i t gral The integ al of Lebe gue w ll b d s d bel w Th t gr l f D njoy includ b th non ab l t ly on e ge t nt g al nd tl e i teg al of Lebesg

Multiple integrals Th c cept call d the R e m i t gral b e t ded t f ncti n f e l a bles Th f a fu ct n of tw al l ill trat ffi ntly the dd t nal feature h h a e To beg w th l t $f(\ y)$ den t a r al fun t d fi ed n recta gl

$$R\ a \leqq \ \leqq b \qquad c \leqq y \leqq d$$

Let P be a p rt t n f R into non erl pp ng ectangles R w th ar A nd l t $(x\ y)$ b a po t f R S t

$$S = \sum f(\ y)A$$

I a th m S t d t defi it l m t I when th m m m d g n l f ect ngl R t nd to ze th f i d t be tegrable o R and th l mit I lled th R t gr l f f r R It ll t de ote l h by th abbre ted symbol

$$\iint f$$

I ropert es r pond g t thos umb d ( ) t l a be p d f th d bl t grals e pt th t pr p rty ( ) h ld w e d a foll w ( ) If th ect gle R s the um of tw ect ngl S l T then

$$\iint_R f = \iint_S f + \iint_T f$$

Nec sary d uffi nt o d t s f a fun t f( ) t be nt g bl e R be t ted a f l l w f bo nded R nd th t f po t wh f d scont be e l ed res f ec t gles th m f wh r as i b t r ly n a t

T d f th nt g l l a fu t n f(y) a m g l d m D h t d fi ed ppo e th t D l sed a ecta gl R a d t

$$F(\ ) = f(\ ) \quad D$$
$$F(\ y) = 0 \quad t \ \ D$$

Then f is said to be i t grable over D in ca e F is i tegrabl over R and

$$\iint_D f = \iint_R F$$

by defin tion

Wh n the funct on $f(x\,y)$ i continu us on D and s d fi ed by inequal t es of th form

$$a \leqq x \leqq b \qquad \alpha(x) \leqq y \leqq \beta(x)$$

wh e th funct ons $\alpha(x)$ and $\beta(x)$ ar continuous the double i tegral f f ver D always exi ts and may be epre ent d in term of two mple integral follows

$$\iint_D f = \int^b\left[\int_{(\ )}^{\beta(\ )} f(x\,y)\,dy\right]dx$$

In many s th s f rm la makes possible the eval uat on of th d ubl nt gral

Improp r mult ple tegrals ha be n defined a ari ty of way Th re is n t spa e to discu the e d finit on a d their rel t ons here

Line surface and volume integrals A gen ral d us i n of c rves nd urfaces requires an ex tended treatt The f ll w ng outl ne is re tr cted to the s mpl t case

A c rv may b defined s a cont nuous image of an op n nte al Th s a curve C in the xy pla s gi en by p r of ntinuo s funct ons of on var a bl

$$x = f(u) \qquad y = g(u) \qquad a < u < b \qquad (6)$$

wher as a urve n p c g ven by t iple f ch fun t The mapping (6) s mo e p operly called r pre e tati n f a urve and a cur e is then de fined s a su tabl las f su h r p e ent t ns. Note th t urve (6) s path r the than lo us Fo xample

$$x = \ \ s\,u \qquad y = \ i\ u \qquad 0 < u < 4\pi$$

i the p th go ng twi e around th un t c cl

$$+ y^2 = 1$$

in th unterel kwi d r t on A curve c ll d smooth in c e th f ncti n f and h ve continuous de u es $f'(\ )$ a d $g'(\ )$ wh ch are ne er s m l taneou ly e

Th l ngth of a mooth curv C m y b l fin d a

$$l(C) = \int \sqrt{[f'(\ )]^2 + [g'(\ )]^2}\,d$$

wh n th s teg l ex ts (as p per o imp p r ntegral) Wh n the int gr l d n t t, th l gth f C i id t be fin te Th d fin t f l gth n te ms f th int g l may l e h wn to ne d w th th geom t defi t n in a m el l ge la tha th cla f mo th ry When C h fi it l gth tl posit n ect $[f(\ )\ g(u)]$ appr hes d f t l m t whe u te d to a t b wh ch a the d f th rv C A m th curv h t v ry p t a on ro t nge t e t r $T(u)$ with mpo ts $f'(u)$ d $g'(u)$ so th t the

integrated by elementary formulas When $m > 1$ a term of the form (3) can be written as a sum of terms of the form

$$\frac{\alpha}{(ax^2 + dx + e)^{m-1}}$$

and

$$\frac{(\beta x + \alpha)(2cx + d)}{(cx^2 + dx + e)^m} \tag{4}$$

By the process of integration by parts the indefinite integral of a term of the form (4) can be expres ed in terms of the integral of a term such as (3) with m replaced by $m - 1$ Reduction formulas of this type are given in standard tables of integrals

A rational function of $\sin x$ and $\cos x$ may be integrated by the method just described after the substitution $u = \tan(x/2)$ has been applied This substitution reduces the problem to the integration of a rational function of u Various functions involving radicals can be integrated by means of trigonometric substitutions or by other substitutions which reduce the problem to the integration of a rational function For example by etting $u = a + bx$ one finds

$$\int x^m(a + bx)^p\, dx = \int \left(\frac{u - a}{b}\right)^m u^p \frac{du}{b}$$

and when m is a nonnegative integer the right side may be multiplied out and integrated by the power formula even though p is a fraction

Integration by parts This i a very powerful and important method It follows from the formula for differentiating a product namely

$$d(fg) = f\,dg + g\,df$$

After the terms are rearranged and integrated

$$\int f\,dg = fg - \int g\,df$$

or

$$\int f g'\, dx = f(x)g(x) - \int g f'\, dx$$

where the arbitrary constant as usual has been omitted As an example consider

$$I = \int \frac{2x^2\,dx}{(x^2 + 1)^m}$$

which is a special case of (4) Let $f = x$ $g' = 2x/(x^2 + 1)^m$ Then $f' = 1$

$$g = \frac{1}{(1 - m)(x^2 + 1)^{m-1}}$$

$$\text{so } I = \frac{x}{(1 - m)(x^2 + 1)^{m-1}} - \frac{1}{(1 - m)} \int \frac{dx}{(x^2 + 1)^{m-1}}$$

The indefinite integrals of many of the comm nly occurring functions are given in tables of integrals in handbooks and textbook

The elementary functions are those expres ible by means of a finite number of algel raic operati ns and trigonometric and exponential functions and th ir inver es The integrals of many elementary functions are known to be not elementary so they define new functi ns A numb r of the e are sufficiently important o that their values ha e been tabulated Examples are

$$F(k, x) = \int_0 \frac{dx}{\sqrt{(1 - x^2)(1 - k^2 x^2)}} \qquad (k^2 \neq 1)$$

$$\mathrm{Si}\, x = \int_0 \frac{\sin x\, dx}{x}$$

$F(k, x)$ is called an elliptic integral of the fir t kind. The inverse of $u = F(k, x)$ is an elliptic function called the *sine amplitude of u and denoted by* $x = \mathrm{sn}\, u$ (*see* ELLIPTIC FUNCTION AND INTEGRAL) S me of the nonelementary functions have been included in tables of integrals

Improper integrals This term is u ed to refer to an extension of the notion of definite integral to cases where the integrand is unbounded or the domain of integration is unbounded Consider fir t the case when $f(x)$ is integrable (in the en e defined above) and hence bounded on every interval $[a + \epsilon, b]$ for $\epsilon > 0$ but is unbounded on $[a, b]$ Then by definition

$$\int^b f(x)\, dx = \lim_{\epsilon \to 0} \int_{+}^{b} f(x)\, dx$$

provided the limit on the right exists For example if $f(x) = x^{-2/3}$

$$\int_0^1 x^{-2/3}\, dx = \lim_{\epsilon \to 0} \int^1 x^{-2/3}\, dx = \lim_{\epsilon \to 0} 3[1 - \epsilon^{1/3}] = 3$$

Similarly

$$\int_{-1}^0 x^{-2/3}\, dx = \lim_{\epsilon \to 0} \int_{-1}^{-} x^{-2/3}\, dx$$

$$= \lim_{\epsilon \to 0} 3[(-\epsilon)^{1/3} + 1] = 3$$

When $f(x)$ is integrable on every finite subinterval of the real axis by definition

$$\int^{+\infty} f(x)\, dx = \lim_{b \to +\infty} \int^b f(x)\, dx$$

$$\int_{-\infty} f(x)\, dx = \lim_{b \to -\infty} \int_b f(x)\, dx$$

provided the limits on the right exi t More general cases are treated by dividing the real axis into pieces each of which satisfie one of the conditions just specified For example

$$\int_{-\infty}^{+\infty} x^{-5/3}\, dx = \lim_{\to -\infty} \int^{-1} x^{-5/3}\, dx$$

$$+ \lim_{\delta \to} \int_{-1}^{-\delta} x^{-/3}\, dx + \lim_{\to 0} \int^1 x^{-5/3}\, dx$$

$$+ \lim_{b \to +\infty} \int_1^b x^{-5/3}\, dx \tag{5}$$

Because the second and third of the limits on the right do not exist

$$\int_{-\infty}^{+\infty} x^{-5/} \, dx$$

doe n t exi t Howe er it i sometime u eful to a+

$$\int_C \mathbf{F} \cdot \mathbf{T}\, ds = \iint_S \mathrm{cu\,l}\,\mathbf{F} \cdot \mathbf{n}\, d\sigma \quad \text{(Stokes)}$$

$$\iint_S \mathbf{F} \cdot \mathbf{n}\, d\sigma = \iiint_V \operatorname{div} \mathbf{F} \quad \text{(Gauss)}$$

In the form la of St kes F s a ve tor field S ı a smooth surf having a pı cewı e mooth boundary c rve C d ected so th t S l es to the l ft of an ob- s rv p oceed ng al g C on the s de f S n which th n t n rmal cto n s cho n and T ıs tl e unit ta g nt vect r t C In t rms f the compon nts f F Stoke formula may be w itte

$$\int_C F_1\,dx + F_2\,dy + F\,d = \iint_S (F_3 - F_2)\,dy\,d + (F_1 - F_{3x})\,d\,dx + (F_2 - F_1)\,dx\,dy$$

wh re $F\,y = \partial F\,/\partial y$ and so on When the rf ce S l es ın the xy pl ne thı quation r duces t Green form ıla

$$\int_C F_1\,dx + F_2\,dy = \iint_S (F_{2x} - F\;)\,dx\,dy$$

The latt r t re dıly pr ed for regions S of simpl shape a d from ıt St k s fo mula may b d duced

In th f m la of G u (als e lled the D ver ge c Theorem) V ı a pace d m ın bou ded by a mooth or p c wı m oth su fa e S and n ıs the e t r o rm l f S In term of th omp n nt of F Ga formula may b wr tte

$$\iint_S F_1\,dy\,d + F_2\,d\,dx + F_3\,d\,dy = \iiint (F + F_{2y} + F_3)$$

5 ■ Calculus of vectors

Functions defined by integrals Ment ha al eady bee m de of llipt fu ct o wh ch may be d fi ed th n e e fu ctı s of ell ptı ntegral Cert n d fin te ıntegr l m y lso b u d to define mp rt nt on l m t ry fun tı s wh h cc fre- q ently n appl atı For example th gan ma f nct on may be d fned by

$$\Gamma(\;) = \int^{\infty} e^{-t} t^{\,-}\; dt$$

f r > 0 Th Be s l f t n f ınt gral o de m y be d fined by

$$J(\;) = \frac{1}{\pi}\int \cos(nt - \quad n\,t)\,dt$$

f r all l es of Th p operties f th fu ct o m be d d f m these xpr with th help f r u method f d nced aly s u h a th theory f f t n f mpl x a abl S e B el fu ction Gamma function

In g n ral $f/(\;, t)$ ı n ntegrabl f tı n f t $a \leqq t \leqq b$ f ch x th

$$g(\;) = \int^b f(\;\, t)\,dt$$

ı a w ll-d fined fun t on of x Wh n u t ble c n d t a tı fied by the fun t on f the d ı t ve $g'(\;)$ m y be calc l t d by the f rmula

$$g'(\;) = \int \frac{\partial}{\partial}\, f(\;\, t)\,dt$$

This process ıs called d fferentiatı n under the ın tegral sign It ı valıd ın case f and $\partial f/\partial x$ are con tınu us ın $(x\,t)$ f r c $< x \leqq d$ $a \leqq t \leqq b$ where a and b are finite and ev n ın more general ca es Howe er ın the following sımple example ıt g ves a wrong r sult

$$f(x\,t) = x\,e^{-\;\;t}$$

$$g(x) = \int^{\infty} f(\;\, t)\,dt$$

Then $\int_0^{\infty} \partial f/\partial x\,dt = \int_0^{\infty} e^{-} (3x^2 - 2tx^4)\,dt$

whı h ı 0 when $x = 0$ although $g(x) = x$ for all x

Approximate and mechanical integration The d fin t on of the d fin t nteg al ıtself gı es a means of alculatıng ts value appro ımately There re- maın the questı n of a s ıtabl lection of the f nctı nal alu s $f(x)$ f r u e ın th formula (1) It ıs usual to dı ıde the ınterval $[a\,b]$ ınto a numbe n f equal parts of l ngth h (Fıg 2) If the p ınts x_i a e taken at the m dp ınts f the subınte al ne obta ns th m dp ınt f rm l

$$S = h \sum_{i=1} f[a + (\; - 1/2)h] \qquad (11)$$

Fo a c rve that ı conc ve downward this gı es t l rge a v lu

An th r f m la alled the trap z ıdal rul ı d r ed by calcul t n the are b l w a polygo ın s r bed n the graph of $f(x)$ (Fıg 3) Th s f r mula ı

$$T = \frac{h}{2}\left[f(a) + f(b) + 2\sum_{i=1}^{n-1} f(\; + ih)\right] \qquad (12)$$

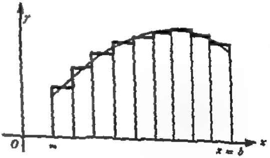


Fıg 2

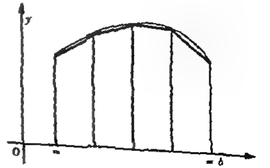


Fıg 3

integrand of $L(C)$ is the length $|\mathbf{T}(u)|$ of this vector Thus one may write $ds = |\mathbf{T}(u)|\,du$ where s is the arc length measured from some convenient point on C

Let $A(x\,y)$ be a bounded continuous function defined on a set containing a plane curve C having finite length Then A determines three functions of C called line integrals whose symbols and definitions follow

$$\int_C A\,dx = \int^b A[f(u)\ g(u)]f\ (u)\,du$$

$$\int_C A\,dy = \int^b A[f(u)\ g(u)]g\ (u)\,du$$

$$\int_C A\,ds = \int^b A[f(u)\ g(u)]|T(u)|\,du$$

If $-C$ denotes the curve C traver ed in the opposite direction

$$\int_{-C} A\,dx = -\int_C A\,dx$$

$$\int_{-C} A\,dy = -\int_C A\,dy$$

$$\int_{-C} A\,ds = \int_C A\,ds$$

so that a reversal of the orientation of C changes the signs of the first two but not of the third of these functions

The extension of the preceding definitions to curves in 3 space is made in an obvious way An important application of line integrals is to express the work done by a force field on a moving particle Thus if a force field $\mathbf{F}(x\,y\,z)$ has components $F_1(x\,y\,z)$ $F_2(x\,y,z)$ and $F_3(x\,y\,z)$ in the directions of the x y and z axes then the work done by the field on a particle moving on a curve C is

$$W = \int_C F_1\,dx + F_2\,dy + F_3\,dz$$

When $\mathbf{T}$ is the tangent vector of C the work W can be expressed in terms of the dot product as

$$W = \int^b \mathbf{F}\ \ \mathbf{T}\,du$$

If $\mathbf{T}_1$ denotes the tangent vector of unit length

$$W = \int_C \mathbf{F}\ \ \mathbf{T}_1\,ds$$

To pa s from curves to surfaces replace the open interval $a < u < b$ by a bounded connected open set D in a ut plane which may be called the parameter plane The domain D can be restricted to be of sufficiently simple shape so that every function which is continuous and bounded in D is integrable over D as a multiple integral For example D may be the interior of a circle or of a rectangle Then a surface S in 3-space is defined by a triple

$$x = f(u\,t)$$
$$y = g(u\,t)$$
$$z = h(u\,t)$$

of functions continuous on D Such a surface is called smooth in case the functions f g and h ha e continuous first partial derivatives in D and the three Jacobians

$$J_1 = \frac{\partial(y\ \ )}{\partial(u\,v)} \qquad J_2 = \frac{\partial(\ \ x)}{\partial(u\,t)} \qquad J_3 = \frac{\partial(x,y)}{\partial(u\,t)}$$

are never simultaneously zero A smooth surface has at every point a nonzero normal vector $\mathbf{J}(u\,t)$ with components J_1 J J_3 and length $|\mathbf{J}|$

The area of a smooth surface S may be defined by the integral

$$\sigma(S) = \iint_D |\mathbf{J}(u\,t)|$$

and it is always finite when the vector $\mathbf{J}$ has bounded length

If $A(x\,y\,z)$ is a bounded continuous function defined on a et containing a surface S with finite area four surface integrals can be defined as follows

$$\iint_S A\,dy\,d\ \ = \iint_D A[f(u\,t)\ g(u\,t)\ h(u\,t)]J_1(u\,t)$$

$$\iint_S A\,d\ \ dx = \iint_D A[f(u\,t)\ g(u\,t)\ h(u\,t)]J_2(u\,t) \qquad (7)$$

$$\iint_S A\,dx\,dy = \iint_D A[f(u\,v)\ g(u\,t)\ h(u\,t)]J_3(u\,t)$$

$$\iint_S A\,d\sigma = \iint_D A[f(u\,t)\ g(u\,t)\ h(u\,t)]|\mathbf{J}(u\,t)|$$

If $\mathbf{F}(x\,y\,z)$ is a vector field with components F_1 F_2 F_3 and $\mathbf{n}$ denotes the unit vector normal to S with components $J_1/|\mathbf{J}|$ $J_2/|\mathbf{J}|$ $J_3/|\mathbf{J}|$ then a combination

$$\iint_S F_1\,dy\,d\ \ + F_2\,d\ \ dx + F_3\,dx\,dy \qquad (8)$$

of the first three kinds of urface integral may also be written in the form

$$\iint_S \mathbf{F}\ \ \mathbf{n}\,d\sigma \qquad (9)$$

where $\mathbf{F}$ $\mathbf{n}$ is the dot product The expression (8) or (9) is referred to as the integral of the vector $\mathbf{F}$ over the side of the surface S to which the vector $\mathbf{n}$ points The integral over the opposite side of S is denoted by

$$\iint_S F_1\,d\ \ dy + F_2\,dx\,d\ \ + F_3\,dy\,dx \qquad (10)$$

and $\quad \dfrac{\partial(\ \ y)}{\partial(u\,t)} = -J_1 \quad$ and so on

and (10) is the negative of (8) The last integral in (7) however is independent of a choice of side of the surface

The important formulas of Stokes and of Gau s are expressed in terms of line and surface integral and the triple or volume integral analogous to the double integral They are

int rval $[a\,b]$ ha mea re zer m ca e it ca be n l ed in a seque e (fin t nfin te) of intervals, the um f wh e lengths i arbitrar ly mall Also a t p-fun t $f(x)$ s def d as ne whi h s con t nt on ea h i terval of a part t n f $[a\,b]$ as in *Fig 4 The Rieman int gral of a t p-funct on i* p es ble a a fi te um The a bo ded fun t on $g(\ )$ i integrable in Lebesgue s en e n ea e t i th l m t of a un f rmly bounded qu nce of tep-funct o s $f\ (x)$ t e h po t of $[a\,b]$ except th n t S w th me s ze o nd by definition

$$\int^b g(x)\,dx = \lim \int^b f\ (x)\,dx \qquad (16)$$

I e se the t p-fu t n f i (16) a e replaced by Lebe gue-i t gr ble f t n form ng a un f rmly bo ded seq nce ew fu cti n g at bt ined

Th i t gr l of Lebesgue s also d fi ed for un b ded f nct on b t the po t f nfin te d sco tin ty do not ne d to be nsidered ne by n For each f ct n $g(x)$ and ea h po it nt g r N let $g\ (\ )$ den te th les r of $g(x)$ a d N If ea h $g\ (\ )$ s Lebe gue t grabl in the al eady defi ed th numb r

$$\int^b g_N(\ )\,d \qquad (17)$$

f rm a o decr s g seq e ce nd so if the n m be (17) a bounded they t d to a finite limit, wh s t k n a the v l e of

$$\int^b g(\ )\,dx$$

A arb t ry fu ct n $g(\ )$ i the d ff r f tw n n gat fu t ns

$$g\ (\ ) = \frac{|g(x)| + g(x)}{2}$$

$$g\ (\ ) = \frac{|g(x)| - g(\ )}{2}$$

d n may et

$$\int g(\ )\,d \qquad \int^b g\ (\ )\,dx - \int^b g^-(\ )\,dx$$

ev b th t m the r ght ha m a ing d g t th defin ti n f t gi en It s pr abl that th la l all fu t f wh h i tegral x t d ng t th d fi ti n ju t g e does fee l ha th perty f mpl t nes with re pect t th Cau hy o dit n (1) Th theo y of

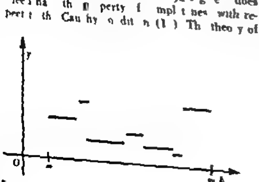


Fig 4

Lebesgue yield man other u eful results includ ing an xt nsi n of the fundame tal theorem of in tegral calculus One mpo t nt restriction on the lass of Lebe gue integrable functions which is im pl cit i the definiti n is th t wh $g(x)$ s integra ble so is $|g(x)|$ This restrict on d e not hold for the imp ope integ al de cr bed in an ea lier p r gr ph

Th r ou metho l of defin ng Lebe gue inte gral ar ext nsible also t functi n of several ar ables Th exten ion thr w l ght n the properties of mult ple Riemann integral and n the reduction of m ltipl integrals to repeated integrals

Other definitions of integration If $\alpha(x)$ is a fixed fu cti n defi ed on the int rval $[a\,b]$ the um (1) may b *repl ced by*

$$S = \sum_{i=1} f(\ )[\alpha(t_i) - \alpha(t_{i-1})]$$

Then f the limit I of S exi ts in thi ca it is c lled the Stieltjes ntegral f f w th respect to α and i denoted by

$$\int^b f(x)\,d\alpha(x)$$

It has m y of the p operties of the emann i te l espe i lly in c e the funct on α n ndecr as ng In addit t may take pec al o nt of the alues f f at a fin te countable t of po t For x mpl if $\alpha(x) = c$ on $u_i < x < u_i$ whe e $u_0 <\ \ > b\ < u < b$ f r $i = 1$ -1 and if $f(x)$ is ont u us at each u_i then

$$\int^b f(\ )\,d\alpha(x) = \sum_{i=1}^{n-1} f(u\ )\{\ _{+1} - c\ \}$$

W th some estr cti to n ure con e g nc this may be xte ded to the ca e when α h s i fin tely many di co tinuit The t a ariat n of the definit on of integral which the am re ult the R man i tegral but which may gi e diff r e t r ults fo th St ltjes i t gral

In the ase wh n α s n nd tea ng the St eltjes nt gr l has xten n whi h is im la to th t of th Lebesgu int gr l and is called th Lebesgu St eltje nt gral

Other xt n *of th Leb g ntegr l* are the i t gral of D njoy They apply to certain functi ns f f r wh ch $|f|$ is n t integrable a d cl de th im pr per t grals but n t the Cau hy p n pal alue me us othe type f integrals ha e b en defi ed In parti l r the nt gral of Lebesgue h be n xt nded to es when the nd nde t bl f es i u tabl pa e o t finit ly many d men s o wh n the f ct nal al es f f lie in u h a p Se CALCULI DIFFERE TIAL AND INTE C L FOURIER SE IES AND INTEGR LS SERIES

[L.M C]

Bibl g aphy E. J B Gours t *A C u s in M th m t cal A alysis* 1917 L. M G a es *Theo y f F n t on f R l V a abl* 1956 P R Halm s *M u Th y* 19 0 G H Hardy *Int g t on of F n t ns f S gl V iabl* 2d ed., 1916 E W

It gives too mall a value for a curve that is concave downward

The error in the approximation may sometimes be reduced without increasing the number of subinter vals by use of the parabolic rule (Simpson s rule) To obtain the formula the subarcs of the graph of $f(x)$ are replaced by arcs of parabolas rather than by line segments Since three points determine a parabola (with vertical axis) the interval $[a\,b]$ is divided into an even number n of subintervals The area under the parabola passing through the points on the graph of $f(x)$ having abscissas

$$a + (2i - 2)h \qquad a + (2i - 1)h \qquad a + 2ih$$

is

$$\frac{h}{3}\Big\{f[a + (2i - 2)h] + 4f[a + (2i - 1)h] + f(a + 2ih)\Big\}$$

so the parabolic rule gives the approximation

$$P = \frac{h}{3}\Big\{f(a) + f(b) + 2\sum_{i=1}^{\frac{n}{2}-1} f(a + 2ih) + 4\sum_{i=1}^{n/2} f[a + (2i - 1)h]\Big\} \quad (13)$$

When a function $f(x)$ is given only by a table its integral is most simply computed by one of these formulas or a similar formula

When a function $f(x)$ is given by a graph me chanical means may be used to calculate associated areas One such means is the polar planimeter which registers on a rotating wheel the area enclosed by a closed curve around which a tracing point is pas ed The inte raph invented by Abdank Aba kanowicz is designed to draw the graph of an in definite integral of $f(x)$ when a tracing point is passed over the graph of $f(x)$ These simple devices were the forerunners of more complex machines de signed to solve differential equations such as the differential analyzer of Vannevar Bush For large cale computations involving formulas such as (11) (12) or (13) a digital computer may be preferred

Other methods of integration The method of differentiation under the integral sign is often con venient for the evaluation of definite integrals e en when other methods are available For example let

$$g(x) = \int_0 e^{x} \, dt = \frac{e \quad - 1}{x}$$

Then $g\,(x) = \int_0 te \quad dt = \frac{ae}{x} - \frac{e \quad - 1}{x^2}$

If $g(x) = \int_0 \frac{dt}{t^2 + x^2} = \frac{1}{x} \arctan\,(a/x)$

$$g\,(x) = -2x \int_0 \frac{dt}{(t^2 + x^2)^2} = -\frac{1}{x^2} \arctan\,(a/x) - \frac{a}{x(a^2 + x^2)}$$

Another example in which the conditions for val d ity of the method till h ld though they are m re difficult to verify is given by

$$g(x) = \int_0^\infty e^{-\ t} \frac{\sin t}{t}\, dt \qquad 0 \leq x < \infty$$

Then $g'(x) = -\int_0^\infty e^{-\ t} \sin t \, dt = \frac{-1}{1 + x^2}$

as can be shown by integration by parts twice Hence $g(x) = -\arctan x + C$ and $C = \pi/2$ since

$$\lim_{\to\infty} g(x) = 0$$

In particular

$$g(0) = \int_0^\infty \frac{\sin t}{t}\, dt = \pi/2$$

In case an indefinite integral is not elementary but the integrand is representable by an infinite series the method of integrating term by term give a representation for the integral which may be u e for purposes of approximation For example

$$\mathrm{Si}\,(x) = \int_0 \frac{\sin t \, dt}{t} = \sum_0^\infty \frac{(-1)\ x^{2\ +1}}{(2n + 1)^2(2n)!}$$

Certain definite integrals may be readily evalu ated by means of contour integrals that is integral of analytic functions taken along curves in the com plex plane

Integral of Lebesgue In the study of the space of real functions defined for example on the inter val $a \leqq x \leqq b$ it is frequently useful to take

$$\int^b |f(x) - g(x)|\, dx \qquad (1$$

as the distance between the functions f and g Th distance already has a meaning when f and g a Riemann integrable that is bounded and not to discontinuous in the sense specified for the Rieman integral There is no generally u eful extension o the concept of integral to apply to all real function on $[a\,b]$ but it is desirable to extend it to apply t the functions obtained from the continuous ones b certain limiting processes In particular it is de i able to ha e correspond to each sequence $(f\,)$ functions satisfying the Cauchy condition for co vergence in terms of the distance (14) namely

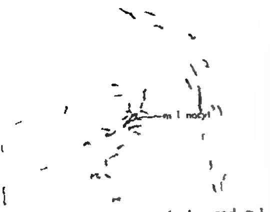
$$\lim_{\substack{m\to\infty \\ n\to\infty}} \int^b |f_m(x) - f\,(x)|\, dx = 0 \qquad (1$$

a function g which is integrable (in the extende sense) and for which

$$\lim_{n\to\infty} \int^b |f\,(x) - g(x)|\, dx = 0$$

An e tended definiti n of integral having this pro erty was gi en by H L Lebe gue in his thesi made obsolete many f the c mplicated exten io of the Riemann integral which had l een previou prop sed F llowi g Lel e g ie arioi mathema cians have pr po d other way f def ning the i tegral whi h ar eq i al nt t that of I el e gue

F Rie z d e l a def n ti n which can l e state q ite imply at lea t f r the ca e of a b inded fun tion $g(x)$ A a first definiti n a poi t set S in th



Fg 2 A d d tc mel ocyt ot th d rmoep d m l l cto l s ct n f th h m k t h gh m g fi t o (ph ec t t pt)

j nct elabo at ng th ir p gment m respon e t loc l nd ti n and thus cont buti g to the c lo f the k n a d its d r t s

M l ocyte A m t e de d ti m la oblast hi h has omme ed th y th t mela in p g m nt (Fig 2) i th mel n cyte It e nt s th e zyme tyr n wh h ataly e th x dat n f tyr dihyd oxyphenyl lan ne to mela n Th m la ocyt may be lled m l noph re but the l tt term doe t p sfy that the ell ha it ll synth the p gm t wh ch t onta n M l n ph res wh ch d ot h w tyr e acti ty hi toch m c l test presumably ha e e gulfed mel n n g an les wh h we e produ ed n mel no ytes

I the h man ski mult bra hed mel nocytes at the d moepid mal jun ti n app ntl sert th r d dr ti p oc e a d tr fer pigment gr n les t th ells f the tratum germ n t m (F g 2) Th p gme t i arr ed t wa d the k n u f ce by pr l f r t f th b sal ells but s grad ll l t du g ke at n zat o The ol d m u t f p gm t njected t th b l ell thu det rm nes t l ge xt t th lo f th k n Th l ghte h m n ra es sh w r latı ly f w a t m la ocytes d espo d gly l ttl p gm t i th t t m g m ati um Fu thermo e th mo nt f p gm nt ynthes ed d depo ted e n e po t loc l d t s i the p derm l b trat m a ffected by h rm nes a d ther fa t rs Th d rke l t s ally p e t th pples, areola ternal g t l p e m a d gro n. Ult i l t y d t pp r tly t at th tyr e l m la ocytes l ad g t i e ea ed p gm t y thes nd d po t o Th g s t ppe ra ce f t n ng nd f eckl g S PIGMEN T TI

Development of the Integument Th tw layer f th kin, pid rm and derm f rm n i t mate a soc at n b t th r g n t d th p d rm dev l p g f om the embry n ectoderm a d th d rm f m th bj nt mesen hym Th ecto-d rmal ets g i at fi t a mpl e bo d l ep thelium By c ll divi ion an ut r l yer of flatte ed cells the p ride m is f rmed ell of the inner l yer *remain* uboid l s bsequ ntly th y divi le formi g the distin ti e t ata f skin a d the pri mordi f the va ous p dermal d ivati es s ch a h r glands nd similar stru t r s In mammals developing ha r penet ate the epide mi nd l ft ff th tough pe derm a c ntinuo s ep trichial sheet

The de m s r co ium rig n t s f om mesen chyme subjacent to the ep d rm s This arises chiefly from the lateral heets of somat me oderm in h gher ert b ates although tl e mesoderm l som t may contr bute cell t the d rmi of the back skin In the head region neural rest cells may pa ticipate in fo m tion of the de m s

The p ospect e derm at fi compri es scat te ed t llat c ll epa ated by embry n c r u d s b tan e and s not eadily d stingu shable f m tiss es dest ed to f m the s bc t neous tis ue muscle a d bone Sub eque tly howeve a com pact l yer f me enchyme of th fibr bl stic type d ffe entiates immed ately beneath the ep derm s p oducing fi st a feltwork of wh te ollage ou fibers and lat na tomos ng llow fibers of el s t n Bl d ve l d rve n ad the co ium f om bel w gla ds a d othe ep dermal d i ati es g ow i to t fr m th v rly ng epide mis

Inte ti ns betwe n todermal nd mes derm l comp nents of the nt gument qu ite to the diff renti ti of th kin and its de i ati es In th hi k *embryo fo* example the pr pectiv de m s is pp rently ncapable of o g nizing either a typ al corı m o th derm l papill e of the f ather germ in the b nc of th e tode m Also n th h ck *egi nal diff* ren es in the cha te i t s of the epid rmal deri t a e cont lled b y fact rs f tl e p specti de mi

Epidermal derivatives These m ctur l mod fic t ns f the p d rmi u h a h s s ales f thers and glands wh h usually ha e a value in adapting the rg n m t its p rticul mode of life E ag t o s f the pid rmi f rm les f atl rs ha ib ae h f claw a d h n The us lly d lop i latio t n nderly i g mesodermal r wh h pro id s th tial tim l t the ep dermal utgr wth I v g at n f th p derm s f rm a a ty of gla ds wh ch ef ec t ng p rti s a e mb dded in the de m *See* GLA

Dermal derivatives Structu al m difie t ons of the d rm e hi fly th e ntr but g t the pro-tect e armo nd sk l tal parts S al of ha ks fi h nd me eptiles are d ri ed f m the d rm s The memb ane bones not bly of the f c and c a n l ult m n n de ed i be f d rmal or gin Vascula modifi at f the derm g e r e t mbe f tructures u h s th omb d wattl b ds and the sexual k f e ta n apes wh h are po ibly f val n xual ec gn t n S PROTECTIVE COLORATION SCALE (ZOOLOGY)

[J W S]

Hobson *Theory of Functions of a Real Variable* 2d ed 1927 B O Peirce *A Short Table of Integrals* 3d ed 1929

Integument

The skin or outer covering of the body together with its various derivatives such as hair glands scales It consists basically of two tissues an outer epidermis and an inner corium or *dermis* The lower layer of the dermis in man and many other animals rests on a fatty subcutaneous tissue or hypodermis which smooths out the contours of the underlying bone and muscle The skin with its derivatives and associated hypodermis comprises an organ system which protects the underlying tissues and according to the mode of life of the animal may serve important functions in respiration excretion water balance protective coloration sexual recognition and others

Epidermis This is the outer portion of the skin It is a many layered epithelium comprising characteristically two distinctive strata of cells the stratum germinativum or basal layer which rests on the dermis and the outer stratum corneum In man the thick skin of the palms and soles shows two intermediate layers the stratum granulosum and the stratum lucidum interposed between the stratum germinativum and stratum corneum (Fig 1)

Stratum germinativum The innermost stratum of the epidermis is the germinativum or Malpighian layer It rests on the dermis and proliferates cells which are added continuously to the outer layers Its basal cells are cylindrical and oriented perpendicularly to the surface of the skin In most vertebrates daughter cells of this layer show a gradual transition to the more flattened cells of the stratum corneum In mammals however there is a striking contrast between the live cells of the stratum germinativum and the flattened cornified cells of the outermost layers of the skin

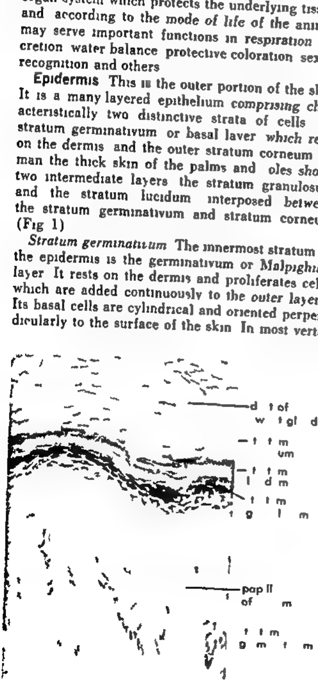


Fig 1 The characteristic strata of the skin of the human finger as seen in cross section at high magnification (From J F Nonidez and W F Windle *Textbook of Histology* McGraw Hill 1949)

Stratum corneum This the outer layer of flattened keratinized cells of the epidermis is particularly well developed in the higher vertebrates It is contributed by cells proliferated from the stratum germinativum As the cells move upward they become flattened and their contents transform almost entirely into keratin The outer layers of keratinized epithelium are progressively cast off as new cells arrive from below

Dermis The deeper layer of the skin is the dermis corium or cutis a dense connective tissue richly supplied with blood vessels nerves and associated sensory organs (*see* SENSE ORGAN) In it are embedded the glands of the skin and other epidermal derivatives such as hairs and feathers The upper surface of the dermis the soft papillary layer is in contact with the stratum germinativum of the epidermis and is thrown into folds and projections interdigitating with local thickenings of the stratum germinativum The papillary layer grades into the denser reticular layer below The latter contains fewer cells and comprises a dense feltwork of collagenous fibers variously oriented but chiefly parallel to the skin surface Elastic fibers are less numerous forming a looser network which is most prominent about the hair follicles and sweat and sebaceous glands Collagenous and elastic fibers of the dermis are continuous with the fatty subcutaneous tissue below *See* FEATHER (BIRD) HAIR

Pigment cells The color of the skin and its derivatives is due largely to the presence of distinctive pigment forming cells or chromatophores in the epidermis and dermis These cells are variously designated according to the color and chemical characteristics of their pigments Chief among them are melanocytes containing granules of melanoprotein or melanin an oxidation product of the amino acid tyrosine which in different cells may range in color from black through brown red and yellow guanophores or iridiocytes filled with iridescent crystals of guanin and a variety of lipophores containing yellow red and orange types of pigment Melanin pigments are chiefly responsible for the color of human skin although carotene and hemoglobin contribute notably *See* CHROMATOPHORE

Melanoblast A prospective melanin producing cell is the melanoblast Originating from the neural crest the melanoblasts migrate to all regions of the body During their dispersal they are indistinguishable from the cells with which they are associated but their presence may be detected by means of proper transplantation or tissue culture experiments In most vertebrates they assume positions in the dermis and at the derm epidermal

S e t glands unl ke h r f ll cle w ll fo m a ew
i art

Th vels t on dee a tlers i an excepti n to th r le that the full thickne f mammal an k n can t be reg nerated Thi layer of typical hair bea g kin pe l ff bef e th antlers are shed b t r ■ ■ rates with the new set of antl rs

[R F BI]

B bl og aphy L B Arey *De elopm tal An t omy* 5th ed 194 W D M El y and H B Cla (ed) *Chemical Basis of Devel pme t* 1958 W M ntagna *The St u tu e a d Fu ction of Sk* 1956 S Rothma *Physiology nd B ochem try of th Skin* 19 4

Integumentary patterns

These e mpr ll th featu es f th kin nd its appe dag th t ar ar anged i des g both i m n a d th r an m l Examples re ale h a d f th r lo ati n and ep dermal ridg s f th fi ge p lms nd feet. In t omm n usag th t rm ppl es t the onfigurati n f ep d rm l r dge e ll t ely med d rmatoglyph c Derma t glyph ■ chara t ti of p im t s

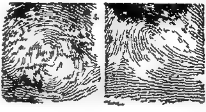
The up ■ l r dges a e a c ated with a spe fi inn r rganizat f k n Sk c mp ed of t ■ f l e ep de m on th out d and the dermi u d rlying it (Fig 1) Tl e two l y r re m tt d l y peg f d rmi a d uble r w of p g rrespo d g t a h idg the e p g e ord ngly f m a p tt m g l k th t f th dge

Ridge patterns The patte n g of dg n lud ng th t f the p dermal-dermal m rti ng is d t m ed d ng the th rd nd f rth f tal m th All h a te i t f ngl dg nd f th ir al g m t th l t rm ed d fin ti ly ll dg al g m t refl t d t ns f tre s g th f th ■ d d foot at th e it al p iod f dg d ff enti t ■ A mp rt nt el m nt i th p od t f localized p tt ns f r example

Fig 1 Structu f ridg d ki (F ■ H C mm d C Mdl F ng P ts P lm d Sole M G w H ll 1943)

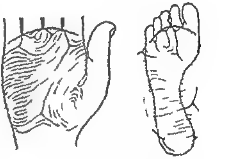
on the terminal segment of each d git is the de el opment in the fetus of a eries of ele ations the lar pad

Volar pads The pad are hom logs of th pr m ne t pad on the paws of me mammals but n primate th y attain little elevation and oon tend to subside (F g 2) Th p ls are di po ed in a con i te t t pographic plan Localized patterns ha e the same plac ment becau ■ growth of the



( ) (b)

F g 2 F ge p t (a) Who l (b) l p (F m H C mm d C M dl F g P t P lm d Sol M G w H ll 1943)



F g 3 D m t glyph c of p lm d sol (F m H C mm d C M dl F g ■ f P lm a d S l M G w H ll 1943)

pad the d termi ■ f th specifi l al p ttern When a pad ha ub d d before ridges ar f med its ar a doe n t p e ent a locali ed pattern and the ridge f llow es ti lly stra ght parall l u V r at ons co t u s of the pads a e ac c mp nied by wide r at on m th des gns f rm d by th dg rlying t.

Pattern variability V rial l ty of patt rn g is a m j r featu of d rmat gl phi s and the ba s for var appl cati ns (F g 3) In personal id ntifi cat pr ts cu toma ly of fi ger are cl s fied f r fil ng in corda with a tables f patt rn typ and co t of r dges Sy temat c fil ng mak s t p ible t l e te r adily nd cor pa e the s ts f print rrespond g in l fi t on to a set ■ wh h an d t fication s ght In anth opolog cal and m d l m e t g t ns g ups f nd id al r e mpared ta t ally in f n to the oc r re ce f thes ariable Deducti may be drawn m da ce w th l k e r l k ness in the d recti of vari t n A few examples are cit d T d f inherita ce h e be n dem nstrated n f m ly gr up and mp r on f the two types

ULTRASTRUCTURE OF SKIN

This aspect concerns details of submicroscopic structures of cellular morphology too small to be seen with a light microscope The electron microscope affording magnifications of 2000–200 000 and ancillary techniques must be employed in this study

Epidermal cell cytoplasm contains in addition to the usual components narrow (about 50 A or 0 005 μ wide) filaments which appear to transform in the stratum granulosum into the solid keratin of the cornified layers Grouping of these filaments or tonofilaments into tonofibrils increases with distance from the basement membrane They are most prominent in thick skins and least in thin skins Tonofilaments made up of prekeratin protein remain intracytoplasmic even within the intracellular bridges or Bizzozero nodules They terminate at electron dense areas subjacent to each cell membrane The two cell membranes within a bridge are separated by a 300 A wide band of amorphous material which changes in the stratum lucidum or lower stratum corneum and is removed as cells desquamate (Fig 3)

The basement membrane is a 350 A thick sheet of amorphous material and associated filaments which completely separates the epidermis from the dermis or corium Collagen fibrils each displaying a characteristic macromolecular striation are found

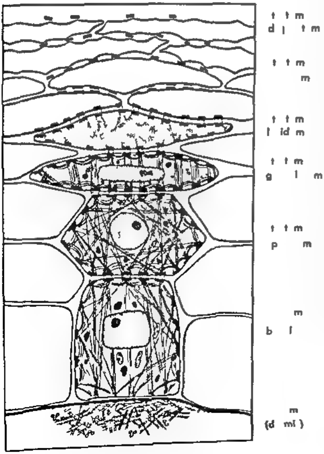


Fig 3 Schematic drawing of the morphological differentiation of the epidermis

individually each 300–800 A wide or grouped as fibers in all intercellular spaces of the corium *See* ANGSTROM HISTOLOGY SKIN *see also* MICROSCOPE ELECTRON [C.C.S.]

REGENERATION

The skin of man and other mammals has a highly developed capacity for regeneration The epidermis, or outer layer is continuously replacing itself through proliferation of its lowermost cells as the cornified epidermal cells from its surface are lost through normal wear The epidermis of the sole of a rat s foot for instance undergoes complete replacement in about 3 weeks

Cutaneous wounds Healing of cutaneous wounds is a regenerative process If a small patch of epidermis is scraped off and a few scattered fragments of its lowermost layer are left epidermis will regenerate rapidly by proliferation of these remaining cells If no epidermal fragments are left, a new layer of epidermis will appear over the denuded area as a result of an inward movement of epidermis from the wound margins Multiplication of the cells present in the new epidermis restores its thickness to normal

Fingerprints a system of ridgelike elevations of the epidermis are regenerated accurately even after complete destruction of the epidermis provided that the underlying tissue is undamaged *See* FINGERPRINT

Deep wounds The capacity of the dermis the tough fibrous inner layer of the skin to regenerate is unfortunately incomplete Lost superficial levels of the dermis are replaced by the activity of connective tissue cells which lay down new collagen fibers If the full thickness of the dermis is excised or destroyed as in third degree burns it is not regenerated All that the body can do is to produce a thick layer of fibrous tissue which eventually becomes covered by epidermis The final product is scar tissue and is quite unlike normal skin Scar tissue lacks resilience and mobility the orientation of its fibers is abnormal and the epidermis never becomes firmly united to it In the early stages of maturation scar tissue undergoes contracture so that the margins of small wounds are brought together and only small scars result Skin grafting is the only satisfactory treatment for extensive loss or destruction of the full thickness of the skin in man Skin is an easy tissue to graft because of its proliferative capacity however the graft takes permanently only if the skin donor is the patient himself or his identical twin

Hair Regeneration of hair depends on regeneration of hair follicles Hair follicles are specialized projections of the epidermis into the dermis They will regenerate completely provided that a small basal fragment remains undamaged This fragment must include the papilla a dermal structure lying at the bottom of the follicle Only in a few animals such as the rabbit under special experimental conditions does scar tissue ever give rise to new hairs

tests lso r flect the al e wh h th pe son pl ces nt llectu l act ty d hı gen al n ed t a hıe e or e el (*see* MOTIVATION)

Desp t the omple ty of the ph ome the ncept of gen al ıntell genc d th tand d ızed tech ıq m f t me reme t tın e to be h ghly u f l s h pract al probl m as th d agno ı f me tal d fi e cy th pred ct o f academ p t tial and s cess a d th elect of perso el n ı d stry d th mil t ry rvı e S e PSYCHOLOGY PHYSIOLOGICAL AND EXPERIMENTAL. [U B]

B bl g phy J B Mı er *I tell ge the U t d St tes* 1957 J P ag t *Th Psychology of Int ll g e* 1950

Intercommunicating system

A teleph e y tem p d ng direct omm t b twee t l ph n the same pr m s of t sh rte ed to ıntercom ch y tems f tw g eral typ s (1) tho t l g regular tel ph s assoc ted with th t wide t l ph tw k d (2) local y t ms ot asso ted with the nat on w d teleph twork B th type ra ge f m s mpl t mpl ın scop

Telephone utilizing systems Int mmun t ı g sy tem t l zı g ı trume ts a c ted w th th nat n w de tel phon tw lly empl y t l pho eq pped with a n mber f key th t a p rt c l r t l ph can be con ted the t a y of er l t l-offi l (or PBX e) or t an ı ter m l Sy t ms mploy ı g h key-eq pped t leph t g th with any r l y l mp d ther related app rat s nd w g e alled k y t l ph e sy t m or n som f m k y eq pm t Th y r furn hed ın wid r ty f embod m t F ample the k y may f m ı t gr l p t f th t leph ne set r may be p at ly m ted S gnal lamps wh h fl h t ı d c te ı com ng c lls, l ght st d ıly d g t d w k wh l a l ıs be h ld m y me a u fo m In ome key

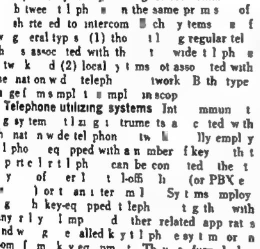


Fig 1 S b k y t l phon (B ll T l ph L b- or ore)

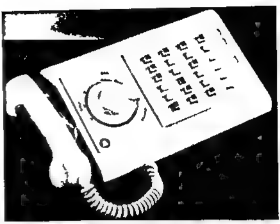


Fig 2 Th rty b tt k y t t (B ll T l ph L b)

t leph e (F gs 1 a d 2) the k y b ttons are m d f tra pa e t plast d ar ll mınat d f om b th th l serv g as visual sıgnals *Se* TELEPHONE TELEPHONE PRIVATE BRANCH CHANGE (PBX)

Th l rger key eq pment ofte t ke the fo m of key t rr t wh h are wood m t l bo es r ng d f de k top mou t (e F g 2) Some t m the keys l mp nd desıgn tion ar ar ra ged a m dula bas so th t additı al nits n b dd d lat f de red Oth key eq ıpme e d gn d f hor nt l ı t llat on an p n ıng at ble t p

Optional features Key equıpments oft n provide for w de ıety f pt nal fe tur The m re mp rta t f th e ar d cu d he e

H ld O e k y wh n pe ted m m nt ıly pla s h ld b ıdge (ually r st) cr s the lı e th t the u e m y temp ar ly tr nsf h s tel ph e set to n ı te com lı e r t a ther en tr l ffi e l PBX e te n w th ut c u g d co e tı n f the ıgı al call He can the t n to the orıgı l ll by r p rat ng the r gı n l h key

I t com ıgnal g By d lı g a on two-d g t cod by pe at ng partı ul r k y par t l r teleph e be ng

C fe c ll g By m lta u ly ope t ng ev al s gn l g k y g o p of t leph can b r ng a d ll who a sw r can e e

P es t f e c c ll g By dıalı g a part cu l one- or two-d g t de p earr ng d gr up of telepho e c n b r ng multa eo ly nd ll wh a swe a c n e se

C mp n Whe ther t leph e erved by the am k y eq pm nt ı dıaled d f d bu y th c lle by n t h ng g up amp n the con nect As oo as the lled telepho e f e ıt w ll be ru aut m tıcally d the waıt g caller will b c n t d he d f a y ther wh m y ha e tr ed to r ach th t p rt cul r t l pho e ı th m nt m

Add-o If all s rec d f om a c t al-offi e l e r PBX e t n ı n (that not ıa nterc m l) nd the lled party w h s t add oth r t le

of twins fraternal (two egg) and identical (one egg) Dermatoglyphics thus are useful in diagnosing the types of twins and in analyzing cases of questioned paternity Among different racial groups the similar or discrepant trends of variation have been used to analyze racial affinities Trends of variation are unlike in right and left hands and the fact that they differ in accordance with functional handedness indicates an inborn predisposition of handedness *See* EPIDERMAL RIDGES FINGERPRINT HUMAN GENETICS SKIN [H CU]

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Intelligence

Defined as the ability to learn to carry on abstract thinking or to adapt to the environment

Intelligence tests However intelligence is defined the ability is almost universally measured by adaptations of the testing method invented by the French psychologist Alfred Binet in 1904 In this method the subject is given a variety of tasks involving such activities as manipulation of symbols the perception of analogies and complex relations the comprehension of causal connections and the solution of verbal and mathematical problems The technique assumes a common background of experience with the mental operations involved so that differences in performance presumably reflect variations in ability rather than in trained achievement but in actual practice the distinction is difficult to maintain Thus intelligence test scores show substantial relationships with highest grade reached in school and with measures of academic achievement Although undoubtedly contaminated by effects of training and experience the intelligence test nevertheless provides a better index of potential ability than any other method presently known to science

Intelligence quotient The results of intelligence tests are ordinarily expressed by comparing the per on s score with the a erage for his age group The measure most commonly employed for this purpose especially with children is the intelligence quotient or IQ This is a ratio multiplied by 100 to avoid decimals of the child s mental age that is the average age at which children achieve the score obtained by the subject and the child s actual or chronological age Intelligence quotients of 60 or below are usually interpreted as indicating mental deficiency while those of 120 or above as reflecting superior mental ability (*see* MENTAL DEFICIENCY)

Viewed developmentally intellectual capacity appears to grow at a declining rate until about fifteen years of age Thereafter although the person may obviously increase his store of knowledge and thereby his skill in the solution of problems in particular areas there seems to be no further gain in absolute reasoning power or capacity to perceive complex relations

Components of intelligence The nature of intelligence has been investigated primarily through statistical studies of the relationships between scores in various kinds of mental task On the basis of such work some investigators following the lead of the English psychologist C Spearman conclude that intelligence is best described as a single general factor which enters in greater or lesser degree into all mental activities A contrasting view championed by the American psychologist L L Thurstone posits a series of six primary factors labeled number verbal pace word fluency reasoning and rote memory The six factors nevertheless show appreciable relations with one another especially at the younger age levels

Since World War II research on the nature of intelligence has shifted from a statistical analysis of content toward the experimental study of cognitive processes such as innovation concept formation and the perception of causality

Bases of intelligence Little is known regarding the physiological and neurological foundations of intelligence Comparative studies of different animal species suggest a gross relationship bet een ability in problem solving and the ize of the cerebral cortex the outer layer of gray matter of the brain but this correlation does not appear to hold within species Injury of cortical ti sue in both animals and men produces a loss in mental function Mental impairment may also be brought about through drugs endocrine malfunction low oxygen supply to the brain or even prolonged isolation from external stimuli for example through immersion of the body for several hours in water at body temperature in a soundproof and lightproof chamber

Attempts to identify the relative contribution and interaction of genetic and environmental factors in the development of intelligence have been made with both animal and human subjects At the human level the classic studies of H H Newman and his colleagues indicate that identical twins reared apart show differences in IQ almost twice tho e obtained for identical twins reared together In the 1950s a growing body of research evidence points to the importance of early experience both before and after birth in the development of intelligence The nature of the intervening mechanisms is not yet known but climatic endocrine and nutritional factors appear to be most relevant in the prenatal period whereas influences associated with prematurity and stimulus deprivation seem most powerful at birth and immediately after *See* BEHAVIO AND HEREDITY LEARNING THEORIES

At later age le els greater attention is being pai to the role of social and motivational factors It i becoming increasingly clear for example that mental de elopment as measured by intelligence tests varie markedly as a function of the family s cultural background and socioeconomic p sition No does it appear likely that the so-called culture free te ts will l e entirely ex mpt fr m thi effect Rather the evidence uggest that along wit[illegible] [illegible] e al il ty and the effects of intelligenc

tests also reflect the alue wh ch the p rs places on i tell ctual act vity and hi gene al need to ach ev o e el (s e MOTIVATION)

Desp te the c mplexity f the phenom no the c pt of g e al i t ll g nce and th tand rd ized tech iq es for ts m as eme t conti ue to be h ghly useful n uch practic l probl m a the d agn of mental defici ncy the pred cti n of adem c pot ntial nd s ccess and the lecti n f pe son el n i dustry nd the m l tary servi es S e PSYCHOLOGY PHYSIOLOGICAL AND EXPERIMENTAL [B]

B bl g aphy J B M n r *I tell g nce i th U d States* 1957 J Piaget, *The Psych logy f Int ll g ce* 1950

Intercommunicating system

A tel pho e sy tem p o idi g d r ct mmun ca t n between tel phone n the s me p em es of t n short ned t inte c m S ch y tem a e of tw g ne al types (1) tho e util zing egul r telephones soc ted with the nat on wide teleph n netw k and (2) lo al ystem ot a soc ated with th at o wide t l pho e etw rk Both types ra ge f om mple t mplex e pe

Telephone utilizing systems Int rcommunic t ng y t m til zing in trume t a sociat d with th t n w d telephone etw rk usually mpl y t leph es equ pp d with n mber of key th t a p rt l t leph ne b c n t d ether t y o e f l e tr l-offic l ne (r PBX ex t n o) or to a inte om l e Sy t m employ t g h key-eq ipped teleph e together with any elay lamp and th r elated pp r tu nd wi ng re alled k y t lepho e y t m or in som f rms key qu pm ts Th y a e furn hed in wid ar ty f mbodiment Fo ex mple the k y may f rm a int g al part f the tel ph ne t r m y be p ately m u ted Sign l lamp h h fl h t d at in m g ll l ght stead l d ring e n ati and wi k whil h e e g h ld may a me a i f rm l ome key

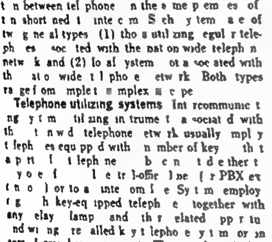


Fig 1 Si -button key t l phone (B ll T l ph e L b or ore)

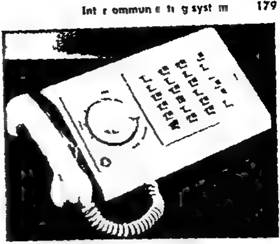


Fig 2 Th rty b tto key t t (B ll T l ph e Lab r)

t lepho e (F 1 and 2) th k y butt ns are m de f tran par nt pl st c and a e illumin ted f om ben ath thus al o rving as v ual ignals S e TELEPHONE TELEPHONE PRIVATE BRANCH EXCHA CE (PBX)

Th l rg r key eq pm nts oft n take the f rm of k y turrets whicl are wood or metal b xe ar ranged f d k top mount ng (*see* F g 2) Some t m s the k y lamps nd d s gnations a e ar r nged on a modula b is th t dditional unit c be added lat r if d ired Othe key equipment r de ig ed f r h r ontal in tallat on in a open g in t bl *top*

Optional features Key eq ipments often provide f r a wide variety of pt n l f atures Th m re imp rt t f the are d cu ed he e

Hold One key hen perated momenta ly pl es a h ld bridge (usually a r *sisto*) cro s the l e so th t the us r may tempor rily t an fer h s tel ph e set t an nte com *line o to a* the *ce tral-offi e li e or PBX* xten ion without cau i g d nnecti n of the rig nal call He c n then re turn to the rig nal ll by r per t ng th origi nal line key

Inte om signal g By d al ng a o e- o two-digit e de r by per ting a part c lar key p t l r teleph ne ca be ung

C nfe e c e ll ng By imultaneou ly perating e e al sign l g keys a oup f telepho es can be r ng nd ll who a swe con s

Pres t co fe calli g By dial ng a p rt lar o e two-d g t ode a p earranged g up of teleph e can be g im lt n ly and all who w r can e r e

C mp-o Wh n anothe tel phone erved by th ame k y qu pm nt is dialed nd f und busy the calle by not h ng g up amp on" the con ti n As soon a th lled telephone i f ee t w ll be ru g automatically and the wait ng ll w ll be connected ahead of a y th who m t ied to e ch th t p rticular tel ph n th m a t m

Add-o If a c ll is rece ed f om c ntral-offi l e o PBX te n (that s n t y a an int com l) d th all d party w h to add ther t l

phones served by the same key equipment to the connection he may do so by operating keys provided for the purpose If he so desires he can then drop off the connection leaving the other party or parties connected

Hands free talking A microphone a small loud speaker means for amplification a suitable transmission network to prevent howling a volume control and two control buttons (ON and OFF) permit two way conversation without lifting the regular handset from its cradle (see Fig 3) The handset can however be used in the usual way when desired This arrangement can be associated with key telephones as well as with ordinary telephones

Privacy Various arrangements are available whereby certain telephones which normally have access to a particular line can be denied access when privacy is desired during a particular conversation One such arrangement utilizes one of the switchhook plungers which is so designed that it can be pulled upward above its normal position The feature is automatically canceled when the handset is replaced on its cradle

Executive access In some key equipments one or more telephones can be arranged so that an executive for example can obtain access to his subordinates telephones whether or not they are busy

With such a large number of optional features available the necessary relay equipment to perform the various functions is usually designed on a building block basis for flexibility

Particular applications Intercommunicating systems have also been developed to meet the need of particular applications such as residences and farms

Fig 3 Key telephone arranged for hands-free talk (Bell Telephone Laboratories)

Residence intercommunicating systems may include such features as local signaling and talking hands free talking and door answering The latter permits residents to converse with anyone who rings the doorbell from any telephone in the house

Farm intercommunicating systems are designed to provide facilities for communicating between residence and barns including the ability to answer or originate calls via the telephone central office. At least one telephone is normally equipped for hands free operation and at least one loud ringing bell or its equivalent is usually provided for outdoor coverage in addition to the regular bells on each telephone

Local systems Local intercommunicating systems not associated with the nation wide telephone network vary widely in size complexity and type of operation In various forms they use most of the other features of telephone utilizing systems although with different technical characteristics

Many such systems contain high gain amplifiers and permit voice paging by direct operation of loudspeakers at subordinate stations under control of a press to talk lever at a master station Usually these loudspeakers serve also as dynamic microphones for speech in the opposite direction Some systems make use of ordinary lighting circuits for voice transmission by using carrier principle to avoid the need for interstation cabling [R F D]

Interface of phases

The boundary between any two phases Among the three phases gas liquid and solid five types of interface are possible gas liquid gas solid liquid liquid liquid solid and solid solid The abrupt *transitions from one phase to another* at these boundaries even though subject to the kinetic effects of molecular motion is statistically a surface only 1 or 2 molecules thick

A unique property of the surfaces of the phases that adjoin at an interface is the surface energy which is the result of unbalanced molecular fields existing at the surfaces of the two phases Within the bulk of a given phase the intermolecular forces are uniform because each molecule enjoys a statistically homogeneous field produced by neighboring molecules of the same substance Molecules in the surface of a phase however are bounded on one side by an entirely different environment with the result that there are intermolecular forces that then tend to pull these surface molecules toward the bulk of the phase A drop of water as a result tends to assume a spherical shape in order to reduce the surface area of the droplet to a minimum

Surface energy *At an interface there* will be a difference in the tendencies for each phase to attract its own molecules Consequently there is always a minimum in the free energy of the surfaces at an interface the net amount of which is called the interfacial energy At the water air interface for example the difference in molecular field in the water and air surf ... r the i t facial energy of 72 erg / ... l s

Th nt rfaci l n rgy betw en the tw l quid benzene and water ı 3ɔ ergs/ m and between ethyl ether and me cury ı 379 erg / m The e nterfac al en rgies a l o expre ed as su fa e ten n n u t of dynes p entumeter

The u face ergy at an nt rf c may be alt red by the add t o of olutes that m grate t the r f e a d modify the m le lar f ces the th f energy may be ha ged by c n rt ng the pl nar nterfacial boundary to a curv d urfa S e ADSO PTION; SURFACE ACTIVE AGENT Both the theor t c l and p a tic l mpl cation of tl s ha g ı u f c e ergy e embod d n the Kel in equ t o

$$\ln \frac{P}{P_0} = \frac{2M\gamma}{RT\rho r}$$

wh re P P_0 is the r ti of the apo e s re of a l qu d dr pl t with d am t r to the po pres u e f th pu e l ı id bulk the d ns ty γ th r f c en gy and M t m le la w ght Th the m ll r th dr plet the g e ter the rel t e po p es r nd a n eq e mall dr plet f l ı id e ap r t mo e r p dly tha la g r nes The rfa nergy f l d ı also funct on of the z a d the K l ı equat can b mod fied to descr be the g at lub l ty f mall part les mp red t th t of la g r p rticle of th me sol d

Contact angle At l q id sol d t fac wh e th θ f the tw pha es ı s ally termed w it g t al f t e lled the t ct angl is l ed A d p f w t pl ed n a paraffin fa f e mpl et n gl bul hape whe ea th sam d f wat pl ed a lean gl ur fa p d o t t s th n laye l th first in th t ngl s pr cti ally 180 and th sec d t n p ti ally 0 Th t dy f t ngl al the t pl y i nte fa al en gies at th bo d r es Th ll t t n ı ach m t r p es nt t f th ı sect f a dr p f l q d a l d There a e ol d l qu d sol d ga and l q d ga nt fa that me t O Th f es abo t O th ı d te m th eq il l ta t a gl r l ted t h th

$$\gamma \quad = \gamma \quad + \gamma \qquad \theta$$

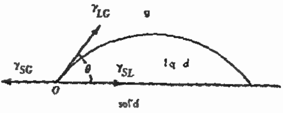
h th γ ı rm p ese t f e n rg e at the t l nd θ the t t a gl S n e aly γLG 1 θ a be m a ed r d ly the t rm adhe n ten d fi ed

$$\gamma \quad \cos\theta = \gamma_{SG} - \gamma_{SL} \quad dh \quad n\ ten\ io$$

Adhes ten n wh h th f nergy f t ı g ıc f rı l mpo ı n d t rg n y d pe f powd nd p gm t l l t d hes l p d ng p oces es

Th m m t f ı ı f l rg es mad d ectly ly po l qu l ga d l q d l y d t fa es In m ı g th l qu d g nt fa ı l en g f f ten l th method f ll ry d p w ght pe d t d p b lbl p es

essil drops Du Nu y ring v brating jets an l ultra nic a tion a e among th used There ı small b t app ec able temp rat r ffe t upon s r fa e t n n and this property ı u ed to d termine small d fferences in th urf e t n on of a l quid by plac ng the two ends f a liquid column in a



Th t ct angl θ t th t rf f th ph

ap ll ry tube wh e tw end ar at diff r nt t m pe at re The determ nat on of ı t rfa ial ener g e t oth r types of nterfac s can be nfe r d only by nd ect m thods See EQUILIBRIUM PHASE FLOTATION FOAM FREE ENERGY SURFACE TEN SION [W H S]

B bli g aphy N K Adam *The Phy ı s and Ch m stry f Surf ces* 3d ed 1941

Interference electrical

Any de ired l tr c l en rgy that t nd to n t rfe e with the rec pt on of des ed ı nals It m y a man made gn l g e ated by nea by elec t ic mot rs aut m t gn t n y tems rad o t an mitt s imp op rly perat ng tele ı ı n ı r wid ar ety of othe impr p rly pe ati g le tr c devi es Th ı terfe nce gnal ith r may be e di t d tl gh spa as unguided lectr ma net c wa may tr vel al ng pow r li gu ded ad ati Interfe ence may lso b au d by tm pheric pl nom na u h as light n ng Su f nat ral distu ban a e m t mes t rr ed fe (NOISE ELECTRICAL) Int fer ı g ig als e som time g n r ted tent nally by po f l tran mitters f r th p rp e of jam m ng c mmuni t o and rada ys ms

Man mad interfer e be t pp e sed t its sou c by ch me n a m n muzing park ng co necti g ap tors a os pa ki g co ta ts h ld i g th eq pment th m tal en los and u i g ch k coils r filt s th t pre ent interf ring g nal f om enter g p we lines S e FILTER, ELEC TRIC SHIELDI G ELECTRICAL [J IR]

Interference filter optical

A opt al filter in wh h the w l ngth that a e n t t an mitted r rem ed by nte f re e phe n mena r th than by ab orpt n o tt ri g (I TERFERENCE OF WAVES) In addit n to be g able t d pl t m st of the pect al characte istics of absorpt c l r filt th se dev ce c n be m d t tra m t a very nar w band of wa e le gths They c n th s be used a m ochr m tors t e m e a rad ı n so r e t the wa el ngth f gl pe trum l ne Fo example th l r d k n be b erved in l ght f th hyd ge l Ha

phones served by the same key equipment to the connection he may do so by operating keys pro vided for the purpose If he so desires he can then drop off the connection leaving the other party or parties connected

Hands free talking A microphone a small loud speaker means for amplification a suitable trans mi sion network to prevent howling a volume control and two control buttons (ON and OFF) permit two way conversation without lifting the regular handset from its cradle (see Fig 3) The handset can however be used in the usual way when desired This arrangement can be associated with key telephones as well as with ordinary tele phones

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Surface energy At an interf e tl ere will be a difference in the tendenc for eacl pha e t at tract it own molecule Con equently there i al way a minimum in tl e free energy of tl e surface at an interface the net amount of whi h i called tl e interfacial en gy At tl e water air interface f r xample tl liff r n e in m le ular f eld in the water an l air urfac a unt f r the inter facial en rgy of 72 erg /cm² a ial surface

If an ther pr sm s brought up to the first, as in F g 4 a part f the light i tr n mitted thro gh th e mb t on The f action t an m tted depends n th eparat o b twe n the pr sms The r fl ctiv ity a be m de as high a de ed In a filter the m hypotenu e m oated with a l w ndex lay r f thi kne cho n to g e the p op r val ie of the refle t ity Thi i co ered w th a high ind x

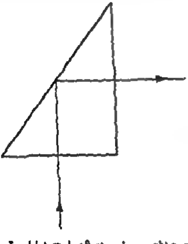

Fig 3 T l l t m l eff ct l ghi-o gl p m

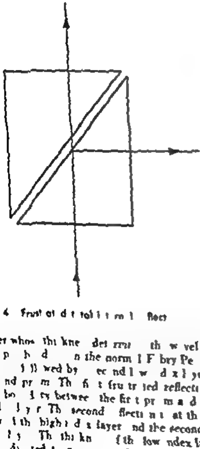

Fig 4 Frust at d t tol l t m l ffect

l yer whos thi kne det rmi th w vel ngth f th p h d n the norm l F bry Pe t filter Th i ll wed by ec nd l w d x l ye and a sec nd pr m Th fi t fru tr ted reflecti at th bo d ry betwe the fir t pr m a d the low d l y r Th second flecti n i at th bo nd a y l th high i d x layer nd the second l w n d l y Th thi kn f th low ndex layer an be dj ted t g a y l of r flecti ty The filter i los l les th r i also pt n with n the lave s The resulting filter can be made to ha e ba dwidth of l ss tha 6 A [B H BI]

Bibliography D E Gr y (ed) *American Insti tute of Phys cs Handbook* 1957

Interference of waves

Th p oce s whereby two or more waves of th same frequency o wavelength ombine to form a wa e wh s amplitud is the sum of th amplitudes of the interferin wa es The interfer ng waves can be electr magnetic acoustic or water wa es or in fact any p r odic disturbance

The m t tr k ng feature f int rference is the effect f add ng two wa e in wh ch tl e tr ugh f one wave co nc de with the peak of another If the two wa s ar f equal amplitude they can cancel e ch the out so that tl e re ulting ampl tude i zero Th s i perh p most dramat in ound wa e t is p s ble to g ner te acousti wa es t arri e at a per n s ear o as to can el o t noise that is *distu bing* h m In opti s this cancellation can occur fo part cular wa elengths in a situation where white light is a urce The result ng light will appe r col r d This gi es rise to the ir d s- cent col rs f beetles w ngs and mothe -of pea l whe the s bstance in olved are a tually color less or t an pare t

Two beam interference Th qua titati e fe t res of the phenomenon can b dem n trated mo t eas ly by c ns d r ng two inte f r wa es The amplitude of the fi st wa e at a part cul r point in p e an be written

$$A = A \ s\,n\,(\omega t + \varphi\ ) \tag{1}$$

wh re A_0 i the p ak ampl tude nd ω is 2π times the f equ ncy F r the second wa e

$$B = B \ s\,n\,(\omega t + \varphi_2) \tag{2}$$

wher $\varphi_1 - \varphi$ i the ph e differen e betwe n th tw wav s In interfe ence th two wa s re u mpo ed and th esulting w ve can be written

$$A + B = A \ \sin\,(\omega t + \varphi_1) + B_0 \ \ in\,(\omega t + \varphi_2) \tag{3}$$

Th s can b e p nded to gi e

$$\begin{aligned} A + B = (A \ \ n\,\varphi_1 + B \ \sin\varphi_2)\cos\omega t \\ + (A \ \cos\varphi\ + B_0 \ c\ s\,\varphi_2)\,s\,n\,\omega t \end{aligned} \tag{4}$$

By etting

$$A \ s\,n\,\varphi_2 + B_0 \sin\varphi_- = C \sin\varphi_3 \tag{5}$$

and

$$A_0 \ \ o\ \ \varphi\ + B \ \cos\varphi_2 = C\cos\varphi_3 \tag{6}$$

Equati n (4) be omes

$$A + B = C\,s\,n\,(\omega t + \varphi\ ) \tag{7}$$

where

$$C^2 = A \ + F \ + 2A\,B \ \ co\ \ (\varphi_2 - \varphi_1) \tag{8}$$

(s SUPERPO ITIO PRINCIPLE OF) Wh n C is less tha A or B the i t fe ence is called d tructi e

and thus the distribution of excited hydrogen over the disk can be determined

Most narrow band interference filters are based on the Fabry Perot interferometer (*see* INTERFEROMETRY) The Fabry Perot interference filter differs from the interferometer only in the thickness of the space between the partially reflecting layers In the interferometer this space can be several centimeters In the filter it is normally a few thousand angstroms In the simplest filter a glass plate is coated with a layer of silver which is covered by a layer of dielectric and in turn followed by another evaporated layer of semitransparent silver

Basic properties At all wavelengths at which the dielectric layer has an optical thickness of an integral number of half waves the filter will have a passband The number of half waves corresponding to a given passband is called the order of the passband The transmission T of the filter can be represented by the equation

$$T = \frac{t^2}{(1-r)^2 + 4r \sin^2 (\delta/2)}$$

where r is the reflectivity of the silver film t the transmission of the film and

$$\delta = \frac{4\pi d}{\lambda} (n^2 - \sin^2 \theta)^{1/2} + 2y$$

where d is the thickness of the dielectric layer n its refractive index λ the wavelength y the phase shift experienced by the light at the metal dielectric boundary and θ is the angle of incidence

By inspection of this equation it is apparent that maxima occur when $\delta/2 = m\pi$ where m is an integer

Some of the quantities which are of interest to the user of these filters are (1) the peak transmission (2) the transmission between peaks (3) the bandwidth and (4) the angular field of view that is the angle through which the filter must be tilted to shift the wavelength of peak transmission a distance equal to the bandwidth

Each of these quantities can be determined theoretically from the preceding equation A typical filter has a peak transmission of 40% at its peak wavelength of 5461 A a transmission between peaks of 0 2% a bandwidth of 100 A and an angular field of view of 20 These numbers represent nearly the best that can be done with the simple metal dielectric filter

Multilayer types An increase in reflectivity can result in narrower bandwidths There are techniques by which high reflectivities can be achieved which are lossless that is which have no absorption This results in higher peak transmission and lower off peak transmission The first is the multilayer filter In this device the metal layers are replaced by a series of dielectric layers The boundary between two dielectric layers of refractive indices n_1 and n_2 has a reflecting power of perhaps 4% in the case of glass and air or less for two dielectrics whose indices are close together The value of the reflectivity r is given by the standard Fresnel reflection law

$$r = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$$

See REFLECTION (ELECTROMAGNETIC RADIATION)

By making several layers of alternate high and low index dielectric it is possible to reinforce the reflectivity of a single boundary and build it up by multiple reflection to any desired value It is necessary only that the layers be of such thickness that the reflections from successive boundaries are in phase When each layer is optically ¼ wavelength in thickness this reinforcement takes place A complete filter is sketched in Fig 1 It might consist of seven alternate layers of high and low index dielectric of a thickness of ¼ wavelength apiece followed by the dielectric spacer which is an integral number of half waves and which is followed by seven more ¼ wavelength layers The characteristics of such a filter are shown in Fig 2 For a seven layer reflection filter the reflectivity can be built up to 95% One would expect improvement over the metal filter and in fact the peak transmission of such a filter is as high as 80% and the bandwidth as low as 5 A

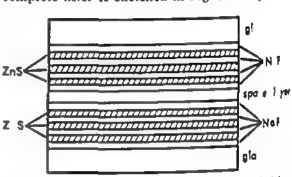

Fig 1 Schematic diagram of 7 layer solid Fabry Perot filter (From D E Gray ed American Institute of Physics Handbook McGraw Hill 1957)

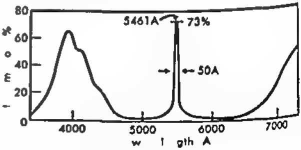

Fig 2 Transmission of filter shown in Fig 1 as a function of wavelength (From D E Gray ed American Institute of Physics Handbook McGraw Hill 1957)

Frustrated reflection A second technique is the use of frustrated total internal reflection for the partially reflecting layers of the filter Light is totally internally reflected when incident on the hypotenuse of a right angle prism as in Fig 3

wa es in Eqs. (1) and (2) s A and B respec ti ely When th pha e sh ft between them i ero the i t n ty f the resulting wave s

$$(A+B)^2 = A + 2AB + B \tag{16}$$

Thi would seem to be a ol t on of the fi st law f thermody am c s this i greater th n the s m of th i d d al i t n it es In any p c fic ex per m nt howe er it t rns out that the e e gy from the so r e t me ely ed tributed in sp ce The ex ces energy which pp a s whe e the int rf ren e i co tru ti e will d s ppear i tho e places wh re the en gy is destr ct e This is illust ated by th fr ng pattern in th Yo ng two-sl t e peri m t. The energy on the s reen from e ch lit l n i giv by the expr ss on

$$E_1 = \int^{\infty} A^2 dy \tag{17}$$

where A i th nten ty f the l ght from each sl t a gi n by Eq (10) The int ns ty from the tw sl t witho t nt feren e would be twic th s val e The inte ty w th i te ference s g v n by th p ess

$$F_1 = \int_0^{\infty} 4A^2 \cos\left[2\pi\left(\frac{yd}{l\lambda}\right)\right] dy \tag{18}$$

The mp r o between $2E$ d E_2 n ed be m d ly a ge rrespond g t o e f ll cycl f f ges Thi m a that th a gum nt f th co- i Eq (18) need be taken ly fr m z r t Th e rr p d t a tt n of sc g ng f m the nt t a d ta e $y = l\lambda/2d$ F om th tw l t nd d ally the e gy n th s ection f sc een n be w tten

$$E_1 = 2\int^{l\lambda/2d} A \, d = \frac{A^2 l\lambda}{d} \tag{19}$$

W th terfe e the energy is

$$E = \int^{l\lambda} 4A^2 \cos^2\left[2\pi\left(\frac{yd}{l\lambda}\right)\right] dy \tag{20}$$

Th a be wr tte

$$F = \frac{l\lambda}{d}\int 4A \cos \varphi \, d\varphi = \frac{A_2 l\lambda}{d} \tag{21}$$

Th s th t tal n gy f ll ng th reen i n t ha ged by the p esenc f i t rf e Th n ergy d ty at a p rt ular po t is h wev r dr tic ll h ged Th f t s mo t import nt f those w es f th lect m g tic p t um wh h be g n r ted t y um t be scill t rs Th so ces f r d t nt a a be m de t em t l t nt w es wh h will n d rg t f en Th m h pos bl a ted t b t f the a f t f z Q i rr w beam f r d at n le p od ed f th proper ph g f l r t a y S A ts (t L)

The d uble sl t expe iment al pro ide a g od illu trat on of Niels Bohr s p inc ple of c mple mentarity F r deta led nformati n n th s s e QUANTUM MECHANICS

Fre el double mi ro A other way of plitting the li ht from the s urce is th Fre n l double mir ror This i llu trated in Fig 2. Light fr m the sl t S_0 f ll n two mirr rs M_1 and M wh ch are incl ed to each oth r at a ngle of the order f a deg ee On a c e n where the illumi at on fr m the two m rro s rl p there will appea a et of interf rence fringes The e are the same a the fri ges produc d n the tw lit e p r m nt s n e *the light on the c en ome f om the images of* th sl ts S_1 d S_2 f rmed by tl e tw m rr rs and these two images are the equ v lent of tw lits

Fr s l biprism A thi d way of plitting the sou ce s the F esnel b prism A k tch of a cross sect n of this d i e is sh wn i F 3 The li ht from the slit at S s tran m tted through th two h l es of the pr sm t the s re n Th b am fr m ach h lf will st ike th scre n at a d ffe ent angle and w ll appe r t e me from so rce which i slightly d splaced f m the o ig al lit The e two al slit a shown n the ketch at S_1 and S The p ation will depend o the di tance of the p ism f om the sl t S and o the a gle θ nd index of r fr ct on of th p m mat l In Fig 3 a i the d stance f the sl t f m the b prism a d l the d tance f the bip m f om th s e Th di tan e f the two v rtual sl ts f m the een is th s $a+l$ The eparat n of th tw v rtu l slit

$$d = 2a(\mu - 1)\theta \tag{22}$$

wh μ is the refract ve index of the prism mate

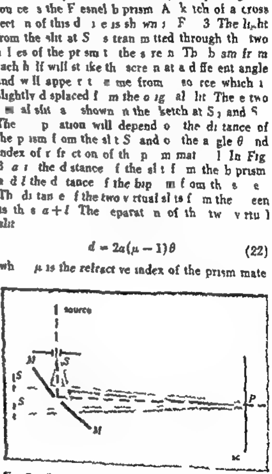

Fig 2 F l d uble-m i t rf c

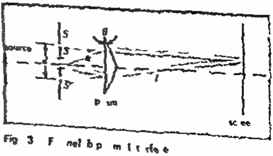

Fig 3 F nel b p m i t rfa e

When it is greater it is called constructive For electromagnetic radiation such as light the amplitude in Eq (7) represents an electric field strength This field is a vector quantity and is associated with a particular direction in space the direction being generally at right angles to the direction in which the wave is moving These electric vectors can be added even when they are not parallel For a discussion of the resulting interference phenomena *see* POLARIZED LIGHT

In the case of radio waves or microwaves which are generated with vacuum tube or solid state oscillators the frequency requirement for interference is easily met In the case of light waves it is more difficult Here the sources are generally radiating atoms The smallest frequency spread from such a light source will still have a bandwidth of the order of 10 cycles Such a bandwidth occurs in a single spectrum line and can be considered a result of the existence of wave trains no longer than 10^{8} sec The frequency spread associated with such a pulse can be written

$$\Delta f \simeq \frac{1}{2\pi t} \tag{9}$$

where t is the pulse length This means that the amplitude and phase of the wave which is the sum of the waves from two such sources will shift at random in times shorter than 10^{8} sec In addition the direction of the electric vector will shift in these same time intervals Light which has such a random direction for the electric vector is termed unpolarized When the phase shifts and direction changes of the light vectors from two sources are identical the sources are termed coherent

Splitting of light sources To observe interference with waves generated by atomic or molecular transitions it is necessary to use a single source and to split the light from the source into parts which can then be recombined In this case the amplitude and phase changes occur simultaneously in each of the parts at the same time

Young's two slit experiment The simplest technique for producing a splitting from a single source was done by T Young in 1801 and was one of the first demonstrations of the wave nature of light In this experiment a narrow slit is illuminated by a source and the light from this slit is caused to illuminate two adjacent slits The light

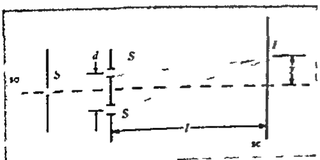

Fig 1 Young's two-slit interference

from these two parallel slits can interfere and the interference can be seen by letting the light from the two slits fall on a white screen The screen will be covered with a series of parallel fringes The location of these fringes can be derived approximately as follows In Fig 1 S_1 and S are the two slits separated by a distance d Their plane is a distance l from the screen Since the slit S_0 is equidistant from S_1 and S the intensity and phase of the light at each slit will be the same The light falling on p from slit S_1 can be represented by

$$A = A_0 \sin 2\pi f\left(t - \frac{x_1}{c}\right) \tag{10}$$

and from S_2

$$B = A_0 \sin 2\pi f\left(t - \frac{x_2}{c}\right) \tag{11}$$

where f is the frequency t the time c the velocity of light x_1 and x_2 are the distances of P from S and S and A_0 is the amplitude This amplitude is assumed to be the same for each wave since the slits are close together and x_1 and x_2 are thus nearly the same These equations are the same as Eqs (1) and (2) with $\varphi_1 = x_1/c$ and $\varphi = x_2/c$ Accordingly the square of the amplitude or the intensity at P can be written

$$I = 4A_0^2 \cos^2 \frac{2\pi f}{c}(x_1 - x_2) \tag{12}$$

In general l is very much larger than y so that Eq (12) can be simplified to

$$I = 4A_0^2 \cos^2 \pi\left(\frac{yd}{l\lambda}\right) \tag{13}$$

This is a maximum whenever

$$y = n\lambda\frac{l}{d} \tag{14}$$

where n is an integer It is a minimum for

$$y = (n + \tfrac{1}{2})\lambda\frac{l}{d} \tag{15}$$

Accordingly the screen is covered with a series of light and dark bands which are called interference fringes If the source behind slit S is white light and thus has wavelength varying perhaps from 4000 A to 7000 A the fringes are visible only where $x - x$ is a few wavelengths that is where n is small At large values of n the position of the nth fringe for red light will be very different from the position for blue light and the fringes will blend together and be washed out With monochromatic light the fringes will be visible out to values of n which are determined by the diffraction pattern of the slit For an explanation of this see DIFFRACTION

The energy carried by a wave is measured by the intensity which is equal to the square of the amplitude In the preceding example of the superposition of two wa the int the individual

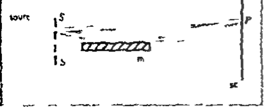

Fig 7 Ll yd m l t rfe

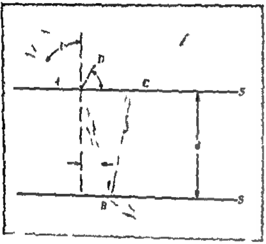

Fig 8 I t f c by fl ct n f m d l ct ic pl

Th pha d ff e I n d s added be a se f th ph f ft pe ienced by th l ght flected at S Th xpe im ntal p of I thi 180 ph se h ft wa l w in tl e des pt n f nte w th Il yd m If th plate of m teri l f w r d x th th medi m wh h it mm sed th d n mt t ll be dded in Eq (31) n w il be m eff ct d at S w ll pe thi xt pha h ft Th pur ly p g m t neces ty f h ddit n l pha e h ft be see l d g th t t n ty f th re flected l ght h tl f S d S lm t en f W th ut th t ph se hift th tw flected beam ll be n ph nd the r flec ld be t g Tl t t t pr f n f lm f an l g th k Con t u tt s m h r m t t g r If th u f d a n If l th f nges will be locat d pt ll t f t If th n t pa llel d w ll f t f po t al ng tl u f es d t t w ll be l c ted n th u f Th t l th fr g w ll l pe d n th l e l th f fle ct ty f th f es f pt f f Observat n of n f Th f t be tested pl c ll fl t pl t M noch r mat

l ght i reflected fr m th two urface and exam ed a in Fig 8 On of th fir t exp r ments with f inges f thi type was performed by S r I aac Newton A con x l ns i p e ed again t a gla s plat and llumi ated with monochr matic light A e s of ci c l r interfere ce fringes known as Newt n s r gs appear a o d th p i t of contact Fr m th eparatio b twee the f inges it i p ble t determin the rad us of curvature of the l n

Th n films I terference f i ges f this two-sur f ce type are re p ible f r the col rs which ap p ar n o l film fl ating o w t r He e the two surface ar th il a r interf ce and the n l water i te face The films are clo e t a is ble light wavelength in thi kn If the thicknes is such that in a particula d r ction destru t ve interfer nce o cur f r gr en l ght r d a d blue will still be eflected and the f lm w ll h a stro g p irple appea an e Thi me ge e al phen menon is re p ns ble f r th c l rs of beetl s w ng

Ch n eled sp ct m Amplit de plitting sh ws cl a ly an th r o dition that must be sati fied for t rf re ce to take pla e The beams fro n the sou ce mu t not nly c me f m identical points but they m st al o rigi ate f om the e p int t e rly the me t me The light wh h s efle t d from C in F g 8 orig ates fr m the o rce later than the light wh h makes a do bl traversal be twee S a d S If the s rfaces a e t f r apart the spect al g s of co t u ti e and d tr cti int rf n become so l se t gether that th y ca ot be e lved In th ca of int rfe enc by w sefr t pl tt ng the l ght fr m d ffe nt part of so ce could only be con dered cohe ent if xamined o e uff ntly h t tim i terv l In the ase f amplitude spl tt ng the nterf rence wh e s rf c s ar w dely separat d ca only be ee if m n d r a uffc ntly na r w fre qu cy int rval If th tw s rface are lluminated w th wh t light and th eye is u ed as the ana ly int fer e ca n t be een when th epa rat n is m re than a f w wa l ngth The nterval between uc es s w l ngth f con t u ti e in t rf r n be me o small th t each spectral re g n t wh ch the eye en ti e illumin t d a d c l r een In thi ca e th terference ag in be see by ex m ng th e ll ct d l ght w th pect scope Th pe t m will be cro ed with t l dark f i g at tho e wavelength s for which th e t d t u ti nt f ence This i c lled a ch nnel d pect m For large parat n of the fa s the parat on betwee the w n l ngth f destr t interference bec me small r than th resoluti n of the spectr meter a d the fr g r n lo g r vi bl

F s l co ff ci t Th ampl t de of the light flect d at n rmal i ci l fr m a d electr su fa i g n by th Fr nel ff ie t

$$A = A_0 \frac{n -}{n_1 +} \qquad (32)$$

rial This can be put in Eq (14) for the two slit interference pattern to give

$$y = n\lambda \frac{a + l}{2a(\mu - 1)\theta} \tag{23}$$

for the position of a bright fringe

A photograph of the experimental equipment for *demonstrating interference with the Fresnel biprism* is shown in Fig 4 A typical fringe pattern is shown in Fig 5 This pattern was obtained with a mercury arc source which has several strong spectrum lines accounting in part for the intensity variation in the pattern The pattern is also modified by diffraction at the apex of the prism

Billet split lens The source can also be split with the Billet split lens Here a simple lens is sawed into two parts which are slightly separated The experiment is sketched in Fig 6

Lloyd s mirror *An important technique of splitting the source is with Lloyd s mirror* This is sketched in Fig 7 in which the slit S_1 and its virtual image S_2 constitute the double source Part of the light falls directly on the screen and part is reflected at grazing incidence from a plane mirror This experiment differs from the previously discussed experiments in that the two beams are no longer identical If the screen is moved to a point where it is nearly *in contact with the mirror* the fringe of zero path difference will lie on the intersection of the mirror plane with the screen The *fringe turns out to be dark rather than light* as in the case of the previous interference experiments The only explanation for this result is that light experiences a 180° phase shift on reflection from a material of higher refractive index than its surrounding medium The equation for maximum and minimum light intensity at the screen must thus be interchanged for Lloyd s mirror fringes

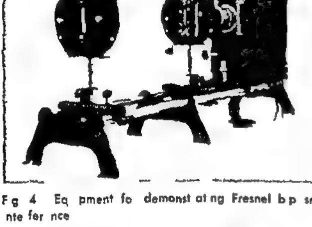

Fig 4 Equipment for demonstrating Fresnel biprism interference

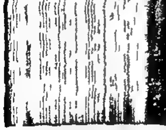

Fig 5 *Interference fringes formed with Fresnel biprism and mercury arc light source*

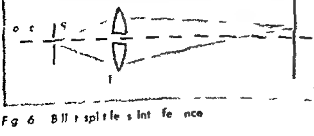

Fig 6 Billet split lens interference

Amplitude splitting The interference experiments discussed have all been done by splitting the wavefront of the light coming from the source The *energy from the source can* also be split in amplitude With such amplitude splitting techniques, the light from the source falls on a surface which is partially reflecting Part of the light is transmitted part is reflected and after further manipulation these parts are recombined to give the interference In one type of experiment the light transmitted through the surface is reflected from a second surface back through the partially reflecting surface where it combines with the wave reflected from the first surface This is illustrated in Fig 8 Here the arrows represent the normal to the wavefront of the light passing through surface S_1 to surface S_2 The wave is incident at A and C The section at A is partially transmitted to B where it is again partially reflected to C The wave leaving C now consists of two parts one of which has traveled a longer distance than the other These two waves will interfere Let AD be the perpendicular from the ray at A to the ray going to C The path difference will be

$$\Delta = 2\mu(AB) - (CD) \tag{24}$$

where μ is the refractive index of the medium between the surfaces S_1 and S_2

$$(AB) = d/\cos r \tag{25}$$

$$(CD) = 2(AB) \sin r \cos i \tag{26}$$

From Snell s law

$$\sin i = \mu \sin r \tag{27}$$

and thus

$$\Delta = \frac{2\mu d}{\cos r} - \frac{2\mu d}{\cos r} \sin^2 r \tag{28}$$

$$= 2\mu d \cos r \tag{29}$$

The difference in terms of wavelength and the phase difference are respectively

$$\Delta = \frac{2\mu d \cos r}{\lambda} \tag{30}$$

$$\Delta\varphi = \frac{4\pi\mu d \cos r}{\lambda} + \pi \tag{31}$$

Fig 7 Lloyd m rr r rf e

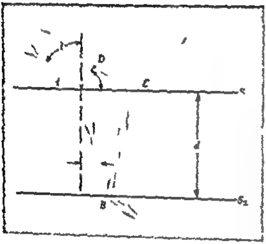

Fig 8 I terf by reflect f m o d l ct ic pl t

The phase d ff rence f r ad a s i added be a se f th ph h ft p ed by th l ght flected t S Th pe im tal proof f thi 180 ph se hift w s h w i th descript n f nt f ence w th Ll d m If the pl te f m t r l h a l w index th n th med m n wh h it mm rsed, th r ad n m t till be dded n Eq (31) w th b am fl ted at S will peri ce th t phase h ft Th pu ly p a m n eces t f h n dd t onal pha h ft be seen b c n d th te ty f the r flected l ght wh th f ces S and S almo t co de W th t th t ph e hift th tw reflected be m w ld be ph a d th flec f film f a h thi k es Co n t e n $\Delta s = \pi$ h e m n t r If th f S a d S a pa all l, th f i ges w ll be loc ted pt ll n fi t If the e n t p ll l d w ll be fi f posit n l g th f c s and th f es w ll be l cated a th u face Th ten ty of th f ges will d pend n th l e f th p rt l eflect ty f th u f es

T l pt al fa Observ t f fri es f th t pe n b used t d t m n th t f a f e The f e t be tested t r t set pt ll fl t pl te M nochr m t l ht i reflected from the two urfa es and e am ned a in Fi 8 One of th fi t experiment w th fri es f thi type wa perf rmed by S r I aac Newt n A c n x len i pres ed again t a gla pl te a d llumin ted w th m nochromatic light A er es of ci cular i te f rence fr nges known as N wt n s ri s appea a ound the po nt f c ntact From the p a at on b tween the fr nge it i possible t determine the rad us of curvature f the l ns

Th film Int rference fringes of thi two- ur f ce typ a e resp n ible for th e ol rs which ap p ar in il film fl ati g n water H r the two u fac are th oil a r int rfac and the o l water interface The film are cl se t a i ible light w len th n th kn If the th ckness i uch th t n a pa ticular d ection destructi e interfer nce occurs f r green l ght red and blue w ll till be r flect d and th film will ha e a tr ng purple ppearan e Th ame g eral ph n menon i re po ibl for the color of beetle wi

Chann led p trum Ampl tude pl tti hows cle rly an the c ndit on that mu t b at fied for inte f re c to take pl ce Th beam fr m the ur e mu t n t only c me fr m id nt c l p nt but they mu t al o riginat fr m th points at ly the ame time The light wh ch s reflected f om C Fi 8 ori nate f m the so rce lat r tha the l ght wl h m kes a d uble tra e s l be tween S nd S If the urfa are t o f apart th pectr l e g ns of c truct and de tructive interfer nce be me so clo t gether that they c n t be resol ed I the a e of i terfere ce by wa ef ont pl tti g the l ht fr m d fferent part of a ou e c uld only be con idered coh nt if exam ed o a ffi te tly h rt t me i t rval In the c se of m pl tude pl tt th interf ren e wh n urfa es e w dely parated an only be se n f exam ed o r a suffi ie tly a row f quen nt r l. If th tw su faces a e illuminated with white l ght nd the u d as th a a l z r inte f en e n t be en when the epa rat on m r tha a f w w ele th The interval b twee c es wa lengths f co truct t fere e becomes o mall that e ch sp ctral r g t wh l th e) s n tt i llum ated and n l ee In th s a th interfe e ce n g in be een by exa n ni the efl ted l ght w th pect cope The pect um will be cros ed w th set f da k f ges t th w i l gths f r wh h th s d t ucti e nte feren e Thi call d a han l d pectrum F larg ep at o f th urf ces th p r t on between th wa e l gth of de-tru t e i te f rence becomes m ll r h th resolut f th spect om t nd th f ges a n f n ibl

F l co ffict t Th ampl t d of th l ght e flected t n rm l id n f om d electri ur f g n b the F es el c effi ent

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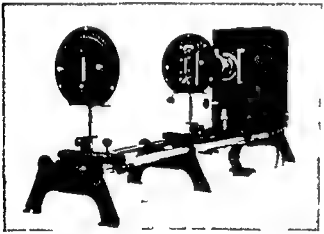
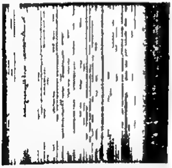
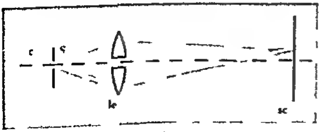


Fig 4 Eq pme t for demonstrat ng F snel b pr m terfe e ce



Fg 5 I te f re ce f ges f m d w th F e el bi p m a d merc ry-a c l ght sou ce



Fg 6 B llet spl t le I t fe e

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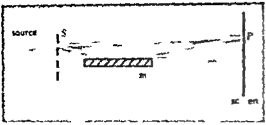


Fig 7 Ll yd' m mt rf e

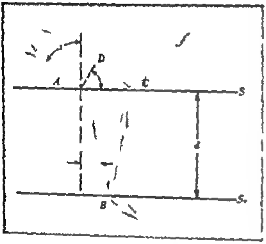


Fig 8 I terf by flectio f m d lect ic plat

The ph d ff f − d n added be se f th ph se h ft p ced by the l ght effect d t S The exp rim t l p oof f th 180 phase h ft wa h wn th des ript of nte f e w th Llo d mirr If the pl te f materi l h a l w nd x th n th med m wh h t imm sed th r d n mu t t'll be dded Eq (31) n w th be m fl ted t S will peri th e t a ph se hift Th p ely p g m t neces t f h n dd ti al pha e h ft a be een by der ng th ten ty f th e- flected l ght when th f S a d S lm t d W th t th t a ph se hift, th tw flected be m w ld be n ph d the r flec t w uld be t ng Th rta nly t p per f film f a hi g th k es Con t rf en w ll t k pl t wa l gth f wh h $\Delta\varphi = 2m$ wh m t g If th u f es S d S ll l th fri ges w'll be loc t d pt If t t fin t If th a t p r ll l d w ll be f t f pos t l g th fa and th f w ll be lo t d th u f e The n- t n t f th f ges w ll d pe d n th l f th rtial flectiv ty f th u faces

T t g f pt al f e Observ t o f ges l th t pe n be u d t d t rm n th f f fa Th u f e t be tested p t lose t pt lly fl t pl t M noch mat

li ht r flected f m the two urfaces and exam ined a in F g 8 O of the first periment with frin es f thi type was performed by S r I ac Newto A n x l ns i pres ed agai t a gla plate and illuminated with m nochr mati light A ser es of circular int rfe e e fringes known as Newt n ings appe r a u d the po t f c ntact. From th p r t on between the fringes it i pos- s bl to d t rm ne the rad us of curvature of the l ns.

Thi films I t rf rence frin es f thi two- ur f ce type a e respo ble for the col rs which ap- p a in l film fl at g n wate Here th two urfaces re the o l a int fa e a d the o l water i terf ce The films a cl se to a i ble light wa elength in th ckness If the thi kness i ch that, in a part cula d rect n destructi e interfer n e occ rs f r green light, red and blue will till be reflected a d the film will ha e a tr ng purpl ppeara ce Thi am gene al phenomenon i re- po ble f r the col f beetles wing

Chann l d pect m Ampl tude pl tting how clearly n ther co d t on that mu t be ti fied for terf n t tak pl e The beam f m the sourc m t n t nl c me f m ident l points, but they mu t l o orig n t f om these po nt at nea ly the same tim Th l ght wl ch i r flected f m C Fig 8 rigin tes fr m the source l t r th n the light which makes a doubl tr ersal be- tween S and S If the u face are too f r apart the spect l r gi n f co tru t a d destructi e nt rfe ence becom o close togeth r that they cann t be esolved I the ase f i terf rence b wa fro t plitt ng the light fr m diff re t part f a so r e could nly be n dered c he e t if ex m ned o r uffi tly sh rt tim int rval In th ca of ampl tude pl tt ng the interfe e ce wh n u f ces a e wid ly sep rated can onl be se if xamined er a uffi entl arrow fre q ency i terv l If the tw urfa es ar ill mi ted w th white light and the ey used as th ana lyze nte fere e a ot be een when th sepa r t n m th few wa l ngth Th nter al between cce-siv w ele gth f co truct n t f bec mes mall th t ach pect al e- gi n to wh h th eye i sen t s ll minated and n col i seen In this c th nterf ce c n a ain be see by x min ng th eflected l ght with pect ope Th pectrum will be cro ed with a et of d k fringes t those w v l gths for which th destruct e te f ren e Th c lled a ch n ele l pectrum Fo large ep r t o f th urf ces the p t o between th wa e- l gth f destru t e t rf n e becomes m ller than the resolut n f th pect meter nd the f nges en lo vi bl

F es l co ffici t The mpl tude of the light flected at rmal incid n e f m a d lectr c ur f ce given by th F es el oeffi nt

$$A = A\,\frac{n - n}{n +} \qquad (3\ )$$

where A_0 is the amplitude of the incident wave and n_1 and n_2 are the refractive indices of the materials in the order in which they are encountered by the light In the simple case of a dielectric sheet the intensity of the light reflected normally will be

$$C = A + B^2 + 2AB \cos \varphi \qquad (33)$$

where B is the amplitude of the wave which has passed through the sheet and is reflected from the second surface and back through the sheet to join A The value of B is given by

$$B = \frac{n_2 - n_3}{n_2 + n_3} \qquad (34)$$

where the approximation is made that the intensity of the light is unchanged by passing through the first surface and where n_3 is the index of the material at the boundary of the far side of the sheet

Nonreflecting film An interesting application of Eq (33) is the nonreflecting film A single dielectric layer is evaporated onto a glass surface to reduce the reflectivity of the surface to the smallest possible value From Eq (33) it is clear that this takes place when $\cos \varphi = -1$ If the surface is used in an instrument with a broad spectral range such as a visual device the film thickness should be adjusted to put the interference minimum in the first order and in the middle of the desired spectral range For the eye this wavelength is approximately in the yellow so that such films reflect in the red and blue and appear purple The index of the film should be chosen to make $C^2 = 0$ At this point

$$(A - B)^2 = 0 \qquad (35)$$

$$\frac{n_1 - n_2}{n_1 + n_2} = \frac{n_2 - n_3}{n_2 + n_3} \qquad (36)$$

$$n_1 n - n + n_1 n_3 - n n_3 = n_1 n - n_1 n_3 + n_2 - n_2 n_3 \qquad (37)$$

This can be reduced to

$$n = \sqrt{n_1 n_3} \qquad (38)$$

In the case of a glass surface in air $n_1 = 1$ and $n_3 \cong 1\,5$ *Magnesium fluoride* a substance which is frequently used as a nonreflecting coating since it is hard and approximately satisfies the relationship of Eq (38) The purpose of reducing the reflection from an optical element is to increase its transmission since the energy which is not reflected is transmitted In the case of a single element this increase is not particularly important Some optical instruments may have 15–20 air-glass surfaces however and *the coating of these surfaces* gave a tremendous increase in transmission

Haidinger fringes When the second surface in two-surface interference is partially reflecting interference can also be observed in the wave transmitted through both surfaces The interference fringe will be complementary to those appearing in reflection Their location will depend on the parallelism of the surfaces For plane parallel surfaces *the fringes will appear at infinity and will* be concentric rings These were first observed by W K Haidinger and are called Haidinger fringes

Multiple beam interference If the surfaces S_1 and S are strongly reflecting it is necessary to consider multiple reflections between them For air glass surfaces this does not apply since the reflectivity is of the order of 4% and the twice-reflected beam is much reduced in intensity

In Fig 9 the situation in which the surfaces S and S have reflectivities r_1 and r_2 is shown The space between the surfaces has an index n and thickness d An incident light beam of amplitude A is partially reflected at the first surface The transmitted component is reflected at S and is reflected *back to S_1 where a second splitting* takes place This is repeated Each successive component of the wave leaving S_1 is retarded with respect to the next The amount of each retardation is given by

$$\varphi = \frac{4\pi n d}{\lambda} \cos \theta \qquad (39)$$

Equation (7) was derived for the superposition of two waves It is possible to derive a similar expression for the superposition of many waves From Fig 9 the different waves at a plane somewhere above S_1 can be represented by the following expressions

Incoming wave	$= A \sin \omega t$	(40)
First reflected wave	$= Ar_1 \sin \omega t$	
Second reflected wave	$= A(1 - r_1^2) r_2 \sin (\omega t + \varphi)$	
Third reflected wave	$= -A(1 - r_1^2) r_1 r_2^2 \sin (\omega t + \varphi$	

By inspection of these terms one can write down the complete series As in Eq (3) the sine term can be broken down and coefficients collected A simpler method is to multiply each term by $\sqrt{-1}$ and add a cosine term with the same coefficient and argument The individual terms then are all of the form

$$Be^{-i\omega t} e^{-im\varphi} \qquad (41)$$

where m is an integer

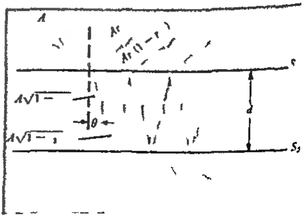
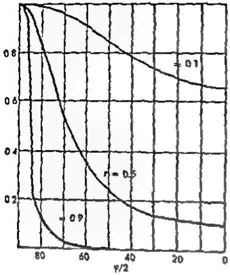


Fig 9 Multiple reflection of a wave between two surfaces



10 Th h pe of m lt ple-b m f g f d f t l f f fl ct ty

n b a ly mmed F r th r flected wa bt n

$$R = \frac{\;+\; \varepsilon^{-}}{1 + \;\; \varepsilon^{-}} \tag{42}$$

n a n tl two-be m a e th n mum n the t ity R i obt d wh $\varphi = N\pi$ wh e N s odd int g d = Tl f ng hap h w n b q it d ff r t from th l e a nd ng th alues of th fl t t s and Th g at th e al th sharp beco f ge

t wa h w rl e how two-b m nterf en ld te u d t me the to f a urfa e th t hn qu a fl t gla test pl t wa pl ced r th rf t be x m d d m n h mat c f n f ges e e form d b tween th te t f e d the f c f the pl te Th e t o m f i g h e t n ti wh h v ry th e q a d of the p th d ffe n It y icult w th h f nge t d t t i t a n ge t ght n th t rm v i ti n of f pla a ty th t re m ll than ¹⁄₁₀ w e gth If th rf t be e am ed s o ted with r nd the t r f e l at d w tl ly t mitt g m t ll at the fle ti t i es t t wh e m y be m e ol ed the f rmat f the nt rf r e f i e Th pe of th f ng s s g n by Eq (42) Th shape f g f d ff r nt v l s f h wn in F g W th h gh fl t ty f ng th se it t t part f m pla ty s n ea d f r beyo d w l gth t i th po bl w th p t lly il d rf c g t a m h bett pi t f m ll g l t s with ted f es Th nc a se ty h th t t ps in l a d m s m ll A n h ght ca be s b e min g th mo o- mat i t f f ng p od ced b tween

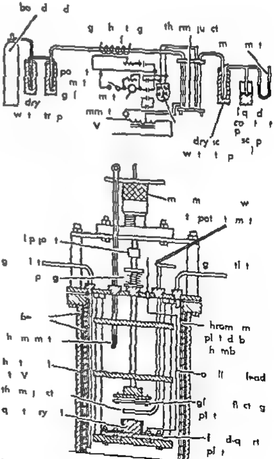
a ilvered mica face and a partially il red gla flat Se INTERFERENCE FILTER OPTICAL IN TERFERO IETRY [B H BE]

B bl o aphy M B r and E Wolf *Principl s of Optic* 1959 O S Hea ns *Opt cal P operties of Th Sol d F lms* 19 5 F A Jenkins and H E Wh te *Fund m ntals of Phys cal Optics* 3d ed 1957 J St o g *Conc pts of Clas ical Opt cs* 19 8

Interferometer acoustic

A device f mea uring th v l city nd att n iatio f ound wa e i a gas or l qu d It operates by s nding an ltra n c beam of s nd wa es thro gh the med um t be mea u ed in der to obtain a di g w e sy tem between the dri ing cry tal nd a r fl t r who e di tance fr m the crystal can be a ed by a c ew sy te n Th illu tration show a typ cal system f r tudyi g the v lo ty and tenuatio of a ga at vario tempe atu es The t p pa t of th llustratio show a sy tem for purify g the g s which th n adm tted t th interf ro- m tric chambe sh wn at th bottom The wl le n t i placed in a therm tated b ting co l which m k t p ibl t regul te the temperatur w th clo e l m ts

An o llat r s ttached t the rystal nd tuned t the ry t l re nant fr que y The ariat n in



A t nt rf m te f m g th l city and tt t f d w g

the amplitude of current from the oscillator is measured as the distance between the crystal and the reflector is varied. At half wavelength intervals sharp dips occur in the received current indicating that a high mechanical impedance is impressed on the end of the vibrating crystal by the standing wave system between the crystal surface and the reflecting plate. By counting the number of half wavelengths n occurring in a given displacement l of the reflecting plate and knowing accurately the frequency of vibration f one determines the velocity of propagation v by the formula

$$v = \frac{2lf}{n}$$

The attenuation can be determined by the rate at which the maximum and minimum current values change with distance. Such instruments can measure velocities to within 1 part in 10 000 and attenuation values within a few per cent. *See* ULTRASONICS. [W P M]

Interferometry

The design and use of optical interferometers, devices in which interference of light is used as a tool in metrology and spectroscopy. These uses include precise measurement of wavelength, the measurement of very small distances and thicknesses by using known wavelengths, the detailed study of the hyperfine structure of spectrum lines, the precise determination of refractive indices, and in astronomy the measurement of binary star separations and the diameters of stars. Optical interferometers are based on both two-beam interference and multiple-beam interference. They are also based on wavefront splitting and amplitude splitting.

Rayleigh interferometer Perhaps the simplest type of interferometer is the Rayleigh interferometer which is essentially a modification of the instrument used in Young's double slit interference experiment (*see* INTERFERENCE OF WAVES). In Young's experiment the two slits are on the order of 1 mm apart. In the Rayleigh instrument (Fig 1) the two slits S_1 and S_2 are of the order of 1 cm apart and ½ cm wide. They are illuminated with parallel light from a lens L_1 at whose focus is a single narrow slit S. A second lens L_2 spaced several centimeters from the first brings the two beams to a focus where interference fringes become visible. The instrument is used to measure the refractive indices of liquids and gases and in this fashion can serve also as a means of chemical analysis.

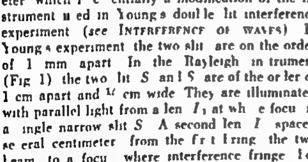


Fig 1 Rayleigh interferometer

Cells (C_1 and C_2 in Fig 1) are placed in front of each slit and matched so that when empty the central bright fringe in the interference pattern is undisplaced. The material of interest is then placed in one cell and the comparison material in the other. If the refractive indices of these two materials are different, the fringes will shift, and this shift is a measure of the index difference.

To make the fringe shift easy to detect, the cells are built to cover only half of the length of each slit. At the focus of the second lens there will accordingly appear two sets of fringes separated vertically from each other. One set involves a part of the beams which does not pass through the cells. It remains motionless when a gas or liquid is put into either cell and acts thus as a series of reference marks for the displacement. In front of the cells are two plates of glass P_1 and P_2. These add a retardation $(\mu - 1)t$ to each beam where μ is the index of refraction of the glass and t is its thickness. One of the plates can be tilted, thus adding a phase shift to one of the beams. When the phase shift is equal and opposite to the phase difference in the beams caused by the refractive index difference between the contents of the two cells, the fringes will be displaced back to the zero position. They will then match the fringes produced by the beams which do not pass through the cells. In this way the instrument can be operated in a null fashion and becomes much more precise than if an attempt were made to measure the fringe shifts with a scale.

The Rayleigh interferometer is an extremely sensitive tool for the detection of impurities in gases and solutions. With 100 cm cells, helium in air can be detected at a concentration of 60 parts in 10^6. This represents an index difference of approximately 1 × 10

Michelson stellar interferometer This device solves most dramatically the problem of measuring the diameters of stars which are as small as 0.01 sec of arc. This task is impossible with an optical telescope since the resolution obtainable even with the largest is not much better than 1 sec of arc.

The Michelson stellar interferometer is a simple adaptation of Young's two-slit experiment. In its first form two slits were placed over the aperture of a telescope. If the object being observed were a true point source, the image would be crossed with a set of interference bands. A second point source separated by a small angle from the first would produce a second set of fringes. At certain values of this angle the bright fringes in one set will coincide with the dark fringes in the second set. The smallest angle α at which the coincidence occurs will be that angle subtended at the slits by the separation of the peak of the central bright fringe from the nearest dark fringe. This angle is given by the expression

$$\frac{\lambda}{2d} = \alpha \qquad (1)$$

wh e d s th eparat n of the sl t λ th d mi nant wa ele gth of the two ur e and α their an gular p ratio Th measur me t f th separa ti of the our e i p rf rmed by adju t ng th p rati n d b tw e the slit until the fring n h

Con de w a singl ource in the hape of a l t f fi te width If th lit subt nd an ngle t th t l ope pert e wh h i la g r than α the t te fer f inge w ll b red ed in ntra t F r ari l lements at one de f tl lit there will be f ment an angl α way whi h will can l th f ing fr m th fi t eleme t By induc t n it l a that for a epa at d d uch that th l t u e btends an a le

$$\alpha = \frac{\lambda}{d} \tag{2}$$

the f ges f om a n l l t w ll am h m pl tely F r add t n l f m t on n th M chel on t lla t f m t s DIFFR CTION

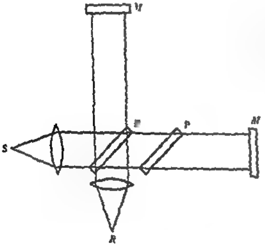


Fig 2 M h l i t m t (F m A C H dy o d F H P Th P pl f Opt M G w H ll 1932)

Michelson interferometer Th M hel n te f m t (F g 2) i ba ed on ampl t de pl tt ng Light f m na w ngl u S i id nt at 45 n a 50% p rt ally fl t g plat P H lf th light t a mitt d to mi or M whi h refle ts t b k t th 50% flect g pl te Tl l ght wh h r fl t d p x d t M wh ch fl ct it b ck t P At P the tw w s a g n part lly r fl t d nd p rt lly t n mitted nd a p rt of h ws p oceed t th r R whi h ma be a r ph t ll a h man ye Dep ding n th d ff e c b tw e th d t n e fr m th be m pl tt t th m r s M and M the r be m will t rf n t tt el o d struct vely Th plat P' mp t f the th kn s f P

Wh th m rr rs mag a compl tely p al l l the i t rf nc f g s are i l Th ffec ti ty f th m m th M h l n t rf rome t r can be m d high a d ed a d the interferenc will till be two-beam interference The int n ty f the fri ges can accordingly be made ery g at If the m rror ar sl gl tly incl ned about a ert al a is vertical fr nge are fo med ro s the fi ld of vi w The e fringe can be f rmed in wh te light if the path differen e in part f the f eld of view s made z ro Ju t as in other in terfer ce experiment only a f w fringe will ap pear in whit l ght beca e the d fference in path will be differ nt for wa el ngths of diffe ent colors Acc rd ngly the f ing s will appear col red cl e to zer path difference and will di appear at larger path d ff rences wher th e tral eparat on of the ce ive r gions f con tru tive interferenc is too clo e for the eye to ee color Th f inge of ero path diff ren e i black and n l e a ily d t g i hed from the n ighboring fri ges Thi mak s u e f the in trum nt relat vely ea y The n iti ity to weak l n a d re luti n of the inter feromet r i thu p t nt ally ry much g eater tl a that f an opti al *spectr meter*

Etal ns As a m as ing de i the m rror M i u ually mounted n a crew that the path d ffer ence an be alt red As the crew i turned the f inge appear t m e and may be c nted F r l ght of the requ red deg ee of m no hromati ity the path diffe ence betwe n M and M_1 can b m de ev ral ce timete l f e the fri ge b come too wa h d out t ount

The red l e of cadmium wa di covered by A A M h l on to be narrow r th n any ther u ce ava lable at the t m One of th early u e M chel on made of h s d v ce w s n the me rement f the tand rd met r in t rm f th s r d cadm um l e The m r or M was r pla d f r the p rpose by p i of mi ro s m u ted a in Fig 3 This a rangement s te med an talon The talo mirrors w f such s that two et lons c uld be pla ed de by s d in the field f view

Se ral f the etal s we bu lt Each w s tw e th length f th next small r The large t w s 10 cm and the s alle t 0.0391 cm F r t the malle t was t up al n and the mi ro M ad j st d w th h t l ght til the bl k fringe was c nt r d At this po t the m ror M and one mi ror f th et lon were equ di tant fro n th beam pl tt W th r d dm m light the m ro M_1 w s

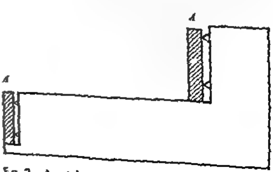


Fig 3 A t lon w th tw dju t bl m rs A a d A' f w h th Mich lso i t rf omet d s t m m t

then moved and fringes counted until the distance of mirror M_1 from the beam splitter was equal to the distance from the beam splitter of the mirror at the other end of the etalon. This operation gave the length of the smallest etalon in terms of the red cadmium line. The second etalon was then placed beside the first and their end mirrors aligned with the interferometer until both showed the black white light fringe. This signified that the two mirrors were exactly the same distance from the beam splitter. The movable mirror M_1 was then shifted until the white light fringe appeared at the other end of the smallest etalon. This etalon was then moved until the white light fringe appeared in the mirror at its other end. It had then been shifted a distance exactly equal to the separation between its two mirrors. Again mirror M_1 was moved until the black fringe appeared in the mirror at the other end of the etalon. This mirror was then separated from the scan mirror of the second largest etalon by a distance equal to twice the length of the smallest etalon. If the larger etalon were exactly equal to twice the smallest, a white light fringe would appear in its mirror also. With monochromatic light it was easy to count the fringes which represented the differential between the two mirrors. A repetition of this procedure with larger etalons gave an exact measure of the length of the 10 cm etalon. The meter was then measured by repeating the mirror alignment procedure with 10 successive shifts of this longest etalon. By a recent repetition of these measurements the length of the meter was determined to be 1 553 164 1 wavelengths of the cadmium red line in standard air.

Interference spectroscope. The Michelson interferometer is also interesting as a spectroscope. Consider first the case of two close spectrum lines as a light source for the instrument. As the mirror M_1 is shifted, fringes from each line will cross the field. At certain path differences between M_1 and M the fringes will be out of phase and will essentially disappear; at other points they will be in phase and will be reinforced. By measuring the distance between successive maxima in fringe contrast, it is possible to determine the wavelength difference between the lines.

This is a simple illustration of a very broad use for any two-beam interferometer. As the path length t is changed, the variation in intensity of the light coming from an interferometer gives information on the basis of which the spectrum of the input light can be derived. The equation for the intensity of the emergent energy can be written

$$I(t) = \int_0^\infty I(\lambda) \cos^2 \frac{\beta t}{\lambda} d\lambda \qquad (3)$$

where β is a constant and $I(\lambda)$ is the intensity of the incident light at different wavelengths λ. This equation applies when the mirror M_1 is moved linearly with time from the position where the path difference with M_2 is zero to a position which depends on the longest wavelength in the spectrum to be examined. From Eq. (3) it is possible mathematically to recover the spectrum $I(\lambda)$. In certain situations, such as in the infrared beyond 1.5 μ, this technique has several advantages over conventional spectroscopy. The detector looks at all wavelengths 50% of the time. The integration time is equal to one half the length of time taken by the whole scan. In a conventional infrared spectrometer the integration time is the time taken by the monochromator slit to traverse one resolvable unit of wavelength (*see* INFRARED SPECTROSCOPY). For a discussion of the use of the Michelson interferometer in the celebrated Michelson Morley experiment, *see* LIGHT.

Fabry Perot interferometer. A simpler device than the Michelson interferometer is the Fabry Perot interferometer, sketched in Fig. 4. The two glass plates are partially silvered on the inner surfaces, and the incoming wave is multiply reflected between the two surfaces. Hence the device is called a multiple beam interferometer.

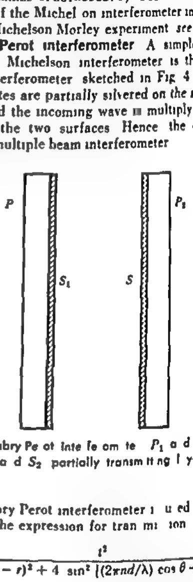


Fig. 4. Fabry Perot interferometer. P_1 and P_2 glass plates; S_1 and S_2 partially transmitting layers of silver.

The Fabry Perot interferometer is used in transmission. The expression for transmission T is

$$T = \frac{t^2}{(1 - r)^2 + 4 \sin^2 [(2\pi n d/\lambda) \cos\theta + \gamma]} \qquad (4)$$

where d is the separation of the surfaces, θ the angle of incidence, γ the phase shift for a reflection at the silver surface, t the transmission of the silver surface, r its reflectivity, and n the refractive index of the air between the plates. When a monochromatic light source is viewed through the interferometer, it will appear as a series of rings. These occur at those angles which make

$$\cos\theta = \frac{(m\pi - \gamma)\lambda_0}{2\pi n d} \qquad (5)$$

where λ is the wavelength of the light and m is an integer.

If a series of spectrum lines is transmitted through the instrument at the an n l a

fringe with order number m m y overlap a fringe f o de $m+1$ a oci ted with a c d line Two l n wh ch would o erlap ex ctly ar gi en by the eq t s

$$\lambda = \frac{2nd \quad \theta}{m} \qquad \lambda_2 = \frac{2nd\,c\;s\,\theta}{m+1} \tag{6}$$

The diff n e can be w itt n

$$\Delta\lambda = \frac{\lambda_1\lambda}{2nd\;\;os\,\theta} \tag{7}$$

I term of w s number and at mall angles of i c dence th s eq t n ca be simpl fied t

$$\Delta = \frac{1}{2nd} \tag{8}$$

An i t rf r meter f sep r ti n d c n be used pectr graph wl e e f a freq ncy i terval Δ the is n o lapping Th s qua tity is alled the f ee sp ctral ra g The re lut n i given by th sep r t n f two w le gths wh e fringes o rlap t th 50% el tive tran m po nt Thi epar tion c b written

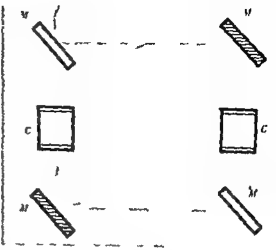
$$d\lambda = \frac{2\lambda\;\;\mathrm{in}^{-}\;\{(1-\;\;)/(2\sqrt{\;\;})\}}{m\pi - y} \tag{9}$$

A int esti g e p i n is the es lut on n t rm of free p t al ange Whe y i neglected thi g n by the f rm ila

$$\frac{d}{\Delta} = \frac{2}{\pi}\,\mathrm{si}^{-1}\left(\frac{1-r}{\sqrt{\;\;}}\right) \tag{10}$$

R fl ct *ngs* The er pr al of this num ber the esol i g p we i term of f ee p ctr l ng n b d d a mea u e f the perfo m an e f a set f Fab y P r t pl tes used pect o- gr ph c lly W th a outs e l r o t g the e- sol ng pow n term of f ee pectr l ang i of the d f 20 H gh r effect ties an mp e th s number b t th t a mi on f th c t g d p t u h les l th t the xp e tim b om s too l ng High lvi p w l b g ns to p t ry t nge t r q me t n th flatne s nd moothn of th pl te Temp r t a d g es- t s d ng th xp ure tim w ll lso ffect the r lut n On way f imp g th in i f m t th gh the u e f m lt ple d lec t l y n pl e of the ev p ated l r r fl t g t A typ l l e l y ha t an mi n f 4% nd effect tv f 93% W th a d lectric ati is the flect ty e r ge f eve l h d ed g t m be a h gh as 99% a d the t m 98% S **E REFLECTIO** (E CTRO IAG- E IC R I Y) RE LVING POW (OPTICS)

Sp r l *g* It d ffi lt t a h with a pect gr ph sol g P e that h gh th f w h nd ed f th s d Th p ctr l r nge h eve an be seve al th a d g t om A F bry P t nte f m ter s fr qu tly u ed in t th a pect g y h th t a i gl pect l l n fr m th pect g aph is esent th mallest



Fg 5 M h Z h d r int rf met

f ee spectr l range req i ed of the nt rf rometer In th fa h n re of i g powe s of se eral m lli n can be a h eved and the hyperfine tru ture and isotope hifts of atom c pectra ha e been disco e ed and st d ed

Mach Zehnder interferometer The M ch Zehn de i t rf r met r ketched in Fig 5 is a a iat n f the M hel o nt rfe m ter a d l k the Mi helson in trum nt depend ampl tud pl tti g f the w efr nt L ght ente s the i trument and is fl ted a d tr m tted by th m tra parent m rr r *M* The refle ted port on proceeds to *M* wh e it i reflected tl ugh the cell C_2 to the emi t an pa ent m rror *M* Here it mb nes with the l ght tran m tted by *M* to p od c nt fer nce The l ght t a m tted by *M* p es th ough a c ll *C* which i mil to C_2 and s u d to compe ate fo th wind ws f C_2

Th m jor appl ation f th s in trument i n studying flow a ou d models f ai craft mis- s le o p jectiles The obje t and a oci ted a r t am r pla ed in o e arm of the int rferometer is au th a p s re s a it fl ws o r the mod l the i d x f r f ct n ar and thu the ffe t path length f the l ght n th s beam is a fu t on of p t on Whe th ia t n is an odd umber f h lf wa es the l ght w ll nt fe e d stru t ly d da k fr ge will appea in th fi ld f w From a phot graph of the f ing s the fl w patt n c n be mathemat cally deri ed

This appl c t on h w the two main feat s wh h d ti gu h th i st um t f om th M chel s n nte f m ter The l ght goes thr ugh a h path in the i str m nt only nce whe ea i M chelson s d i th l ght tra er es ch path twice Th do ble t l make th Mi h lson te f omet xt emely diffic lt to us n appl t ons wh e pat al lo t n f nd ar at o s de i ed The i com ng and outgoing b ms t nd to tr el o e l ghtly d ff ent p th a d thus lowe s the r ol t o bec e of th i d x grad ent ac the field I th M helson int rfer met r th

fringes are located at the virtual intersection of the two reflecting mirrors. In the Mach-Zehnder device the mirrors can be adjusted so that the fringes are located at the plane of the model being studied. In this fashion they can be photographed simultaneously with the model so that their geometric position with respect to the model can be precisely determined. *See* SHOCK WAVE DISPLAY. [B H BI]

Bibliography: *J phys radium*, vol 19, no 3, 1958; J Strong, *Concepts of Classical Optics*, 1958; S Tolansky, *An Introduction to Interferometry*, 1955; W E Williams, *Applications of Interferometry*, 1930.

Intermediate frequency amplifier

A tuned amplifier employed in the amplification of the signals produced by the mixer in a radio receiver. Because the carrier frequency of the modulated signal from the mixer is essentially constant, the resonant frequency of the amplifier is a fixed value.

The proper design of the intermediate frequency (i f) amplifier is essential for good selectivity and reproduction of the original transmitted signal. If the amplifier is tuned too sharply, the high frequency components of the modulating signal will be lost. To avoid this, stagger tuning of the individual stages may be used. In a stagger-tuned amplifier the resonant frequency of each stage is slightly different from the carrier frequency, with the result that the gain is essentially constant over the bandwidth of the modulated signal. The gain decreases rapidly at frequencies outside this band.

The standard i f frequency for broadcast radio receivers is 455 kc; other frequencies are used depending upon the particular application, such as television receiver or radar receiver. *See* AMPLIFIER. [H F K]

Intermetallic compounds

If two metals are melted together in certain proportions, the result is generally an alloy. It is also possible to form alloys by solid state reaction or by application of the powder metallurgy technique. Depending on the component metals and their proportion, the alloy may consist of a single phase or of several phases. Single-phase alloys may be either of the solid solution type or intermetallic compound. According to the *Handbook of Metals*, an intermetallic compound is defined as a compound

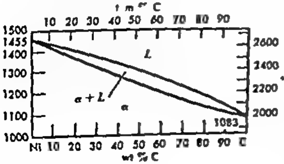


Fig 1 Copper-nickel phase diagram

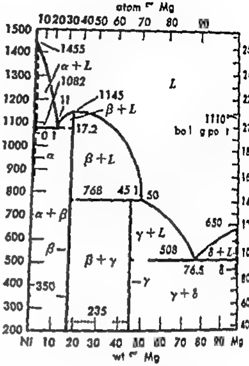


Fig 2 Magnesium-nickel phase diagram

of two or more metals with a characteristic crystal structure and may have a definite composition or range of compositions corresponding to a solid solution.

The difference between solid solution alloys and intermetallic compound can be t le sh wn b comparison of characteristic phase diagram. Figure 1 shows the phase diagram of two components (for example, copper and nickel) which form a solid solution alloy; a typical phase diagram for two metals which form an intermetallic compound is shown in Fig 2. The intermetallic compound appears in the phase diagram as a vertical line and its structure relationship may be treated in the same manner as a pure metal. The elements present in an intermetallic compound unite in definite atomic proportion similar to true chemical compound, but unlike the chemical compound they do not follow simple valence rules, because all the metals have positive valences.

In the solid solution copper-nickel system all the alloys of the various compositions are of face-centered cubic structure and the lattice parameter varies linearly with the atom concentration of the two components from $a = 3.60$ Å for copper to $a = 3$ Å for nickel, where Å is a constant and is the atom concentration.

Th ination of nickel with magnesium results in two intermetallic compounds, as shown in Fig 2. The β phase is of the pre t ermetallic compound Ni_2Mg and the γ phase is precisely $NiMg_2$. The two components in this system are of close-packed hexagonal structure (Mg) and of face-centered cubic structure (Ni), where, for example, in the intermetallic compound ($NiMg_2$) the atoms are hexagonally arranged. The interatomic distance for the intermetallic compound $NiMg_2$ is 4.81 Å, whereas the distance for Mg is

3.2028kX and for N 3.5167kX The intermetallic c mpou d th efo e differ co de ably n den s ty hardness trength ductil ty nd ther pr p erti s fr m the ompon t f om wh h they a e f rmed They ha e be om f e ade able te hn cal a d e t fic i te e t bec u e f the elatively h gh melti g po nt and ox d t on re tance of cer ta n int rm tallic compounds

I rec nt yea inte t h s e nt r d n inter metall c compounds f rmed of an el ment fr m gr p III of the p riodi table w th an elem nt of gr p V Comp und f thi type sh w sem c n duct ng pr pert e very imil r t th el mental emic nd t rs german um sil c n and gr y t n f gr up IV F r xample i di m a tim ny (I Sb) s ery milar to gray tin in its p pert es su h a lattice pac ng rag atomi we gl t and the e f re d ity R ctificat on and tra i to ct o f t rm tall c mp nd f this typ ar of p mary import n e f m te hnol gical p nt of v w S ALLOY ALLOY STRUCTURES CERMET EQUILIBRIUM PHA E NO STOICHIOMETRIC COM POUNDS SEMICONDUCTOR SOLID-STATE CHEMISTRY [H H H]

B bl gr phy Am Soc Metal *M tal Ha d b ok* 1948

Intermolecular forces

Th n g ti grad e ts f the *potenti l ene gy* *F* between tw t ra t g mol l s, *F* being a func t n of th di t n *R* between th cent f the t molec les Th nt rm l c lar f c ar thus p l i in the reg o wh e *F* de e es th *R* (th reg n t the left f th m nimu n th ac mpa g figu) and ttr t wi e e *F* in c e e th *R* (th eg o to the right of th mi m m) Int mol c lar f a con en e tly d ded i t tw J hort r ge fo es a d l g ra ge f c s. The f rm a nfi d to eg l bo t 3 A the latt act b yond th t d t c

Short range forces In the figu th h rt f es a e pul v Th s u ually the a f molec les wh h d n t i t a t ch m c lly Th teeply i i g p rt f the rve n th or gi th n du to th l pp ng of l ct on cl ud a d the fo ces which correspond t it are called ex chang force (a term exp e ng the mathemati al o igi of the force wh ch ari e mathematically from ertain xchange pr pe ties f the m lec ilar e ergy state funct on) Exchange f rces can al o be att act e Th s is the ca e *for atoms which* enter i t ch mi al combination The curve in the figu e then has a ery deep minimum at di t nces of the o der of 1 2 A from the orig n (for the mple t tom) Attracti e *exchange* for es are called vale ce fo c s and play an important r le thr ugh ut chemi try

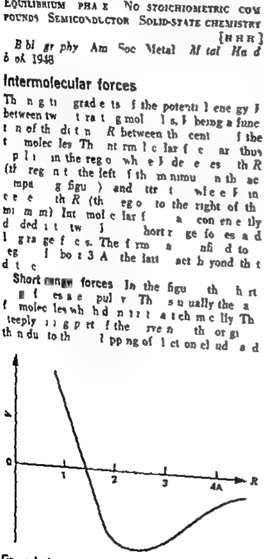
Repuls ve xchange forces acc unt f r the me ch n al rig dity *impenetrability* f m lecule the teepne s of th p tential *energy* c rve in the ex hange-fo ce d ma n gives r e to the l mited comp e *bility of matter*

Long range forces Long ra intermolecular fo ce a e often called Van der Waal forces be cause th y lead to the Van der Waals equat o of tate (e VAN DER WAALS EQUATION) In particu l r the con t nt *a* i that equati n s m a ure of the r st ngth For une c ted nonpolar mole c l s th f rces e attr ctive These f rc give rise to a larg ariety of physical and ch m cal phe omen uch a urface te i n friction ha g s f pha e adhe ion and c hes on f liquid and olid sc sity diffus n th Joule Thom on effect a d th depa t res of ga s fr m the deal g s l w (irial coeffic nt) Van der Waal for es a e f om e ld ffe nt phys al cau es

O g The rig n of the Van d r Waal for es wa once sought in gra itat o l att a t s These a e n w kn wn to be much too m ll to ccou t f r th kn wn intermole ul r effe ts The first c n j tu (P Deby) in l ed the s umpt on th t n f the intera t ng m l ul ca a p rma e t multipol f r example, quadrupole a d ind es by electr c pol r zat n a m ll multipol n th ther Thi a tion k wn s the i duction ff ct, wa hown to le d t attract e f rces Al though t does tak pla e many tanc s it i t o m ll to acc nt f th full tr ngth f th Van d Wa l fo es nge r l

If b th mol ul have permane t p lar ty the m lt p les te d to al gn th m l es nd th eby gi e to attract e f ces This alignme t effect (W H Ke m) mpo ta t part f th Van d r W al f es betw pola m l ules b t d es t xpl th f r s b tween nonp la r u tu

The m g fact is f nd upo appl ati f quant m the ry to m lec lar i ter ctions It m y b de bed foll w in g l th el t on m l ul r l e ap dly and in a m ne unc el t d w th th l ct on c m t ns i oth r m l ule but wh n two m lecules re br ght fa ly l e t g th th l t o t ti fi ld t up by th m ng electr c n t i the m t ns n the tw m le l t b mo e or le s in pl e the ph agr me t be g clo the m lle th d t n e betwee i tera i g m l c les Att acti e f t s res lt, the fo c b ng c ll d d pe



Ge ral h ract f f m l ul f urve

forces (F. London). At large distances of separation the potential energy associated with dispersion forces is proportional to $-R^{-6}$.

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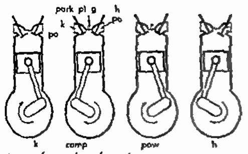
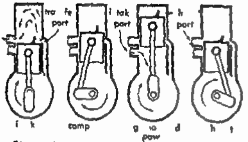


( ) fou roke-cycl po k g on g



(b) three-port type f two-cycl

Fig 1 ( ) The f t k f m de fo r t k n g cy l F t k t k th t k l e (l ft) h op d d th p t m g d w w d d w g d go f p to th cyl d l m p o t k th t k l h l sed a d th p to m g pw d mp g th m xtu D pow t k th g t y t m p d e o p k th t g t the m t A t b h gh p t d wh ch p h s th p t d w w d Fo h u t t k th e h u t l (ght) h p d d th p t n m g pw d f g th b ed g se f m the cyl d (b) Th m o t cc m pl h d w th t sep t of d m gl t f l th k h ft by th e-p rt two-cy le m g e (F m M L Smith a d K W St F l d C mb st McG w H ll 1952)

E g n u i g th two- t ke y le t day h be f rth mpl fied by u f third c l d r p rt wh h d p w th th r nk a heck l e ed by Day S h ngi es w de s f r mall u t wher f el e n my n t m port nt a mecha al mpl city a d l ght weight. Th y d t ed mecha i ally ope ut d al nd de lop ne mbu t n cycl p k h ft revo- l t n Nev rthel they d n t des lop tw e the pow of f t ke cy l w th the me ze w k g cyl de r th am n mb of o- lut pe m te (pm) Th pri ipal o s for th (1) th ed t o n ffe t e cyl d r l me d e t the p t n m em qu ed t o th exh u t port ( ) the app ec bl m x ng f b ed (h t) ga w th the mbu ti bl mi t r nd (3) the l s f e m mb tibl m xt th o gh th exh t ports w th the h u t g se

Otto s engine l ke almo t all internal comb u t on eng nes developed at that per d burn d coal gas mixed in ombu tible proportions w th air pr or to be ng drawn into the cylinder The engi e load was ge erally controlled by thr ttli g the qu t ty f ch rg taken i to the cyli d r Igniti n was accompl hed by a de ce such a an e ternal flam o an electric park s that the tim ng was c ntr llabl The e are e ential features of what has b me known as the Ott o park ignition combu t n cycl

Ideal and actual combustion In the cla cal presentation of the f u tr ke cycle comb tion is ide l ed n tanta eous and at con tant v l ume Th simpl fies thermodyn m c analy is b it f rtunately c mb t on take t me f is doubt f l if an g n oul l un if th whole charge b rned det nated i ta tly Detonation of a small p t f the cha n th yl nder fter mo t f th ch rg has bu ned p ogre i elv c u es the knock wh ch limits the c mp e on atio of an en g ne with n fu l *See* COMBUSTION KNOCK

The g s pr s e f n Ott combu t n cycle u g the fo r t k ngine cycle var es w th the p t n po t n as hown by the typ cal i d cator ard in F g 2a This i a co nt o al p s ure olume (*PV*) c d fo an 8 7 1 c mpre n rat o F r s mpli ty n ale l ti n of ng e pow r the a r ge et pr s ure d ring the work ng t oke c lled th m a ffecti e pre u e (*mep*) fre qu ntly d It m y be obt ned f m the average et h ght of the card which i f und l y meas e ment f th a ea with a pla meter nd by di ion of thi are by its le gth Sim lar pressure lume d t may be plott d l garithmi coord at s as i Fi *b* wh h d el p e p n i n and c mpres- s n l ti a approx mately stra ght l es the sl pe f which how th v l e f exponent t u e i quations f r *PV* rel t o hips

Th roundi g of th pl ts at pe k pr s re w th the p ak de el p ng fter the ton h s started its pow t oke en w th the pa k occurr ng b f re th pi t n rea hes the nd of the c mpre s o t ke due t the t m qui ed for combustion The tual t me requ red is more r le under on th l f th ng e d sig hec e h c n alter th d ign to v ry the i l e of th t rbule ce of th ha ge i the mp e i n pace p t and d r ng combu t The g ter the tu b l n the f t r th e mb sti a d the lower the a t k ock o ta e al e req ed f th fuel or the h gh th mpres on ati th t may be u ed with a g en fuel w th ut kn cki g (s e COMBUSTION CHAMBER COMPRESSION R TIO) On the the hand a des g e m lim t d as to the amou t he can rai e th turb l n e by the a d r t of p e sure r e wh h ine eases g ne rough es R ghness m t n t ex eed a level acceptable f a tom b le oth r s n

Effect of compression ratio Acco d to l i al thermodyn mi theory th rmal effi e cy y of the Ott mbu t on cy le

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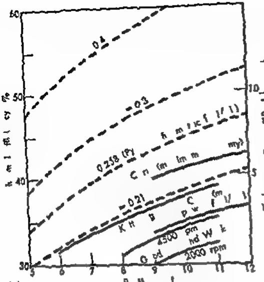

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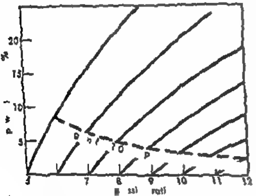


b)

Fig 3 ( ) Eff ct f mp e n to th m l ff cy a l l ted with diff t l f d mp ed with publ h d p m t l d t (b) l cr p w f m ng omp to l c f t d with = 1 3 t g l but l m h d by d ff t l of

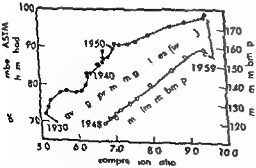


Fig 4 Ye -to-yea f t betw ve g m o t of d ve g oct mb f g l ld t h U d S t

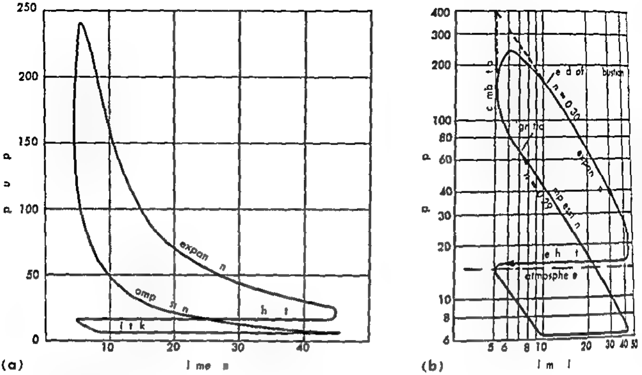
f at all with lo d pt aded th t the fuel air ratio remain constant and that the ignit on time ad van ed at reduc d loads this c mpen ates for the slower ate of burning which lts from d lution of th ombu t ble ch rge with th larger perc nt ages of bur ed e r ma ning in th combu tion pace

Effect of ignition timing Des g ers obtain high thermal eff iene from h gh compre i n rat os at part lo ds whe e engines normally run at automo- bil cru s ng peed w th optimum park ad ance but v id kn k on a a lable ga lines at wide open throttle by use of a reduced or compromi e p rk dv n Th tendency of an engine t knock at w de open throttle is reduced apprec bly wh n the park d an e r duced -10 from optimum as i f wn in F g 5 Advancing or reta d ng th park t ming fr m ptimum results in a cons tent l s i mep for any no mal engi as shown by the s l d urve The octane requ reme t fall rapidly as the spa k timing is ret rded the actual rate de p d ng n th natur of the ga oline as well as on the des gn of the combu tion chamber The dotted curv s A and B h w the ffects o a gi e ga li e of the e of mod rate and high tu bulence com bu tio chamb rs r spect v ly with the *same c m* pr sion ratio B cau e the mep c rve is r lat vely fl t ne r opt mum p rk adva ce retardi g the park for a 1-2 l s con de d normally ac ceptable n pract b c u of the appr ciable re du t on in o tan requ ement

In F g 6 s mila data are sh wn by curve A for noth eng n w th mep pl tted di ectly again t *octa* req i ment as the park timing wa l rged Po nt and c t a pt mum pa k t ming wh e 85 octan w r qui ed of the ga l ne to a o d k ock By rai g the compre sion rat o th p w r nd e req *rem nt* were also a ed as hown by th dotted urve Altl ough opt mum spa k qu d 95 t ne (p nt b) reta ding the sp k t mi g *and thus* edu ing the tan qu re m t t 86 (po t c) de eloped li htly more powe than with the o g al c mpre o rati ts opt mum pa k d a The ga n may be *neg* lig ble at w de op n th ttle b t at lower l ads whe k o k d s not d l p the pa k tim ng m y be d a ced to optimum (p int b) where appre bly m p w r m y b de elop d by th s me amou t ff l

In add t n t th d ntages f the h gher c m p e s o at t ermi i g loads w th ptim m park ad a ce the comp om sp rk t f ll load may be d a d t w d *pt m m s higher* octane f ls be om a a labl a d a c rre pond ng increa e in full th ottl m p njoy d Su h mp om se spark t m g h had m h t do w th th dopt on of mp n r t (f 10 1 f 13 1

Effect of fuel air ratio A s milar l of e s n ng how th t a f el *r mixture* ricl r than that wh h de el ps maximu n knock fre mep w ll pe m t u of higher c mp on r t os H w er th b fit d d f m omp om e or uperr ch mixt res v ry m h w th m tu e t mp r t



F g 2 (a) Typ cal pressu e volume ind cator card plotted on ectangular coordinat s (b) The same data plotted o loga ithm c coo d ates

$$\eta = 1 - \frac{1}{r^{n-1}} \qquad (1)$$

where the compression ratio r and expansion ratio r are the same ($r = r = r$) When theory assumes atmospheric air in the cylinder for extreme simplicity exponent n is 1 4 Efficiencies calculated on this basis are almost twice as high as measured efficiencies Logarithmic diagrams from experimental data show that n is about 1 3 Even with this value efficiencies achieved in practice are less than given by Eq (1) This is not surprising considering the differences found in practice and assumed in theory such as instantaneous combustion 100% volumetric efficiency and so on

Attempts to adju t classical theory to practice by use of variable specific heats and consideration of dissociation of the burning gases at high temperatures have shown that this exponent should vary with the fuel air mixture ratio and to some extent with the compression ratio G A Goodenough and J B Baker have shown that for an 8 1 compres ion ratio it should vary from about 1 28 for a stoichiometric (chemically correct) mixture to about 1 31 for a lean mixture Similar calculations by D R Pye showed that at a compression ratio of 5 1 n should be 1 258 for the stoichiometric mixture increasing with excess air (lean mixture) to about 1 3 for a 20% lean mixture and to 1 4 if extrapolated to 100% air Actual practice gives thermal efficiencies till lower than these which might well be expected because of the assumed instantaneous changes in cyclic pressure (during combustion and exhau t) and the disregard of heat losses to the cylinder walls These theoretical relations between compression ratio and thermal efficiency as well as some experimental results are shown in Fig 3 The data published by C F Kettering and D F Caris are about 85% and 83% respectively of the theoretical for the corresponding fuel air mixtures Figure 3b gives the theoretical percentage gain in indicated thermal efficiency or power from raising the compression of an engine calculated from Eq (1) with $n = 1\ 3$ These gains are less than half as great as those obtained by industry as indicated from the maximum brake mean effective pressure (bmep) values for production cars shown in Fig 4

Experimental data indicate that a change in compression ratio does not appreciably change the mechanical efficiency nor the volumetric efficiency of an engine Therefore any increase in thermal efficiency resulting from an increa e in compre sion ratio will be re ealed by a corresponding increase in torque or mep this is frequently of more practical importance to the engine designer than the actual efficiency increase which becomes an added bonus

Compression ratio and octane rating For years compression rati s of automobile engine have been as high a designers c nsidered pos ible with ut danger of too much cu t mer annoyance fr m detonation or knock with the ga oline on the market at the time (Fig 4) Engine de igners continue to ra se the compression ratios of their engines a rapidly as suital le ga olines me on the market

L ttle theoretical study has been gi en t the effect of eng ne load on indicated thermal efficiency Experimental evidence reveals that it aries little

H gh ntake ai t mpe ture a d d ty mat i ally a d c mbu t n in a d el eng ne, espec ally f fu ls ha i low v latil ty and h gh vi ity Som e gine h e not pe f rmed pr pe ly o y fuel until pro ided with a sup r h rger The added c mpr s o f the p rcharger rai ed the temp at e and what i m r important, the d n s ty f th c mbu ti n air For an Ott engin an n a n e th the r temper ture or d n ty in r a es th t nd y f the engine to kn k and th r f re redu e the allow bl compr n rat o D el ngin s d elop inc ea gly high nd ated thermal effic ency t redu ed load be e f l ane fuel i rat s and rl r e toff Such mixtu e rati m y be lean tha will gn te n an Ott eng Furth rmore the redu tion of l ad i an Otto gine r qu res thr ttl g whi h de elops in rea ing p mp ng l s s in the intake ystem

TRENDS IN AUTOMOBILE ENGINES

E ch y r the powe developed pe cyl nde p k ignit a t mob le g e ha n re ed H ghe omp o t nd refi ed de ign a ount f r th n rea Cyli der d am t r in Am ri can made eng ne d c e ed ap dly at first as m pr m t w re trod ed and th n tabil d at about 3½ i (F g 7) In 1959 a e age American aut mob l e g e d am ter w 3 9 n Many Eu o pe n tom bil ng nes have cylind r bo e d me t r a m ll as 2⅛ 2¼

Bore stroke ratio E p r mental ng nes d ff r i g nly n bo e trok t show that th ti has app ec bl effect on f l eco omy nd fri at corr pond g p st sp eds. P a t al d s tage hi h r ult from a h rt tr k el d (1) the gre t r rigid ty f crank haft f m the ho te a k che k with rankpi m tim s erlapp g m in l a ng a d (2) tl e n rrow r as w ll l ght yl der bl ck whi h is pos bl O the th r h d th h gher t f cr nk haft rot t on f r a equ ale t pi ton peed nece sitate great l e f r es nd eq e tronge l e pr ng Al th sm ll r depth f the compr s on p e f r a g e mp es n t nc ases the u fa to- l me ati d th p oport on f heat l t by r d at n during mb ti n Neve th l s, bore- t oke i h be n in eas g to more

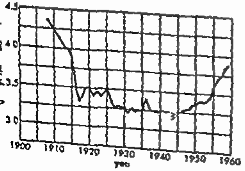


Fig 7 T d i e g cyl d diam t f U ted St mob le g

than 25 y rs and in 1959 reached 1 08 for the aver age autom bile in the Un ted States

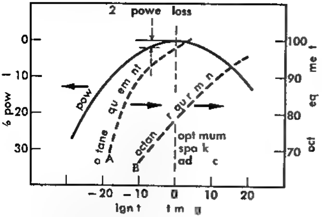
Compression ratio The cons derable increase n engine p wer h be n cau ed by steadily im pro ed d ign Compre i n rati and thus mep have inc ea d (Fig 8)

In 1959 mp es i n ratio of 10 1 r high r were pro ided on m than 36% of all autom bile m del manufa tu ed Such rati s approach pract cal l m t mpo ed by phenomena other than deto n t on uch as preign tion rumble and other evi de s of nde irable combust on

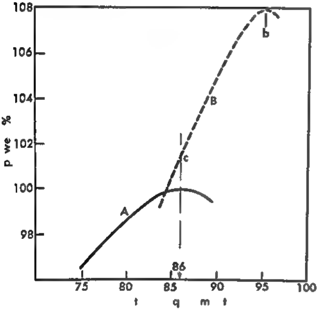
The modern trend toward h gh compre ion t with the r small c mpr ion volumes has dic tated the almost un er al u e of erhead al e in all new r Ame i an engine de gn High mpres ion rati s al o t nd to restr t yl nd r d ameter be u e th lo ger flame tra el increa es the tend ency t knock (F g 9)

Improved breathing and exhaust Added power utput has be n ught al o t by educing the pr sur drop n the intake system at high peed and by reduc g the b ck pres re of th exhau t system (F g 10) These r ults were a compli hed by larger lve a e s and al po t larger v n t ri r as a d by mor str aml ned m n folds La ge al ar as we e achie ed by highe l ft of the l es and by larger al es La g r venturi ar a in the ca bu etor were acl e ed by u e of one m e two- tage carburet s in the e s ffi i nt a r velo ity w devel ped t mete the fuel n one v ntu low pow r the econd ventu was op ned f r h gh powe Better streaml ning f th manif ld pas ag betw en arburet r and val es, e pec ally at th cyl nder p ts, and th u e of dual exhausts nd muffl rs with r duced ba k p es u ha e l mp o ed engi e br athing and exh u t

Cylinder number and arrangement Engin power m y be rai ed by i r as ng th number f yl nd rs a w ll s the wer pe cyl nd r Th m nim m number of yl de s has g n rally been f ur fo f u cy l autom bil g n b c u th s is th mallest numbe th t p des r as abl b lance f r th ecip ocating p stons Many arly cars had fou -cylinder eng nes After 1912 ix-cyl nd r m l g n s b me p pul r They ha e superior balance f recip ocat g f c s and m re ev n t q ump lse By 1930 the eight-cyl inde 90 V engine h d r n popul ty until i bout eq alled the ix l n Aft r 1954 the V-8 d m ted th fi ld f r Ame an aut m b le en g es Th e are e e al important re ons f r this bes d tl e n sed power F r e mple th V-8 offe app ciably mo rigid con tru t on w th less be t g d flect on at high spe ds p ides m f m d t b t on f fuel to all cylinder from cent lly loc ted d wn draft ca bu to s d has h rt low ng ne th t fit with n the hood d m ded by tyl t nds. Th olution f cyl nder arr g me t i luded f r a short pe od th V 12 nd e en a V 16 yl nd r de gn but experience h d that n th r d y th r w s too mu h pra



Fg 5 Effects of ad anc ng or etard ng ign t on tim ing from optimum on eng e powe and the result ng octane requ ement of the fu l in an e perim ntal en g w th a comb st on chamber having typ cal t rbu lence (A) and a h ghly tu b lent d gn (B) with the me comp on rat o Retard g the spark 7 for a 2% powe loss red ced the octane requirement from 98 to 93 for de gn A



Fg 6 Effect of compr s t of a x pe m tal g e on the powe tput a d tan req me t at w de p th ottle Wh l 86 ct f el was qu ed for opt mum sp advance (ma m m p we) w th the o g al comp ess on r t o the same g sol wo ld be kno f t th h gher comp ss o rat o by s t bly reta d g the gn t o t ming

and the sen itivity of the octane value of the par ticular fuel to temperature that it is not generally practical to make much general use of this method Neverthele s it has been the practice with p ston type aircraft engines to use fuel air mixture ratios of 0 11 or even higher during take off instead of about 0 08 which normally develops maximum mep in the absence of knock

Compression ignition engines About 20 years after N A Otto first ran his engine Dr Rudolf Diesel uccessfully demonstrated an entirely different method of igniting fuel Air is compressed to a pressure high enough for the adiabatic tempera ture to reach or exceed the ignition temperature of the fuel Because this temperature is in the order of 1000 F compression ratios of 12 1 to 20 1 are used commercially with compression pre sures generally over 600 psi This engine cycle requires the fuel to be injected after compres ion at a time and rate suitable to control the rate of combustion.

Conditions for high efficiency The classical presentation of the diesel engine cycle assumes combustion at constant pressure Like the Otto cy cle thermal efficiency increa es with compre ion ratio but in addition it varies with the amount of heat added (at the constant pressure) up to the cutoff point where the pressure begins to drop from adiabatic expansion *See* DIESEL CYCLE DIESEL EN GINE

Practical attainments Diesel engines were highly developed in Germany prior to World War I and made an impressive performance in subma rines Large experimental single cylinder engines were built in several European countries with cyl inder diameters up to 1 meter As an example the two stroke Sulzer S100 single acting engine with a bore of 1 meter and a stroke of 1 1 meters de el oped 2050 gross horsepower at 150 rpm Multiple cylinder engines developing 15 000 horsepower are in marine service Small die el engines are in wide use also

Fuel injection In early diesel engines air in jection of the fuel was used to develop extremely fine atomization and good distribution of the pray But the need for injection air at pressures in the order of 1500 psi required expensive and bulky multistage air compressors and intercoolers

A simpler fuel injection method was introduced by James McKechnie in 1910 He atomized the fuel as it entered the cylinder by use of high oil pre sure and suitable spray nozzles After considerable development it became possible to atomize the fuel sufficiently to minimize the smoky exhaust which had been characteristic of the early solid injection engines By 1930 solid or airless injection had be come the generally accepted method of injecting fuel in diesel engines *See* FUEL INJECTION

Contrast between diesel and Otto engines There are many characteristics of the diesel engine which are in direct contrast to tho e of the Otto en gine The higher the compression ratio of a d e el engine the less the difficulties with ignition time lag Too great an ignition lag results in a sudden and undesired pressure rise which causes an audi ble knock In contrast to an Otto engine knock in a diesel engine can be reduced by use of a fuel of higher cetane numbe which is equi alent to a lower octane number *See* CETANE NUMBER COM BUSTION WAVE MEASUREMENT OCTANE NUMBER

The larger the cylinder diameter of a die el en gine the mpler the devel pment of good combu tion In contrast the maller the cylinder diameter of the Ott engine the le the l m tat n from det on ti f the fuel

t cal d ffi ulty in pr ding g od man f ld distribu ti n of fuel e pec ally when t t ng cold nd too mu h d ffic lty in keepi g ll spark plug fir g See AUTOMOBILE

Engine balance Rotating ma ses su h a crank p ns nd the low r h lf of a c nnecting od may be c nte bal n d by w ght atta hed t th crank h ft. Th v br t on wh ch would re ult fr m the ecip ocating for of th pi t n a d the r a o- ci ted ma s is u ally m nim z d or elim nat d by the a rang me t of cylind rs in a mult cyli der e g ne so th t the re ip ocat ng f c s in on cyl de r n utr lized by tho e in an th r Whe th forc s re in d ffere t pl nes a co e pond ng p i of yl nd s i required t ounte a t the lt ng rock ng upl

If p t n m t n w re truly harmoni which w uld r qu a c n ect ng r d of infin te length the r c p ocati rti f c at ea h e d of th strok w uld be

$$F = 0.000456WN s \qquad (2)$$

he W s the t tal we ght of th r c p o at ng p t in e cyl nd r N i the pm a d S th tr ke i in h s Both F and W a e in pou d B t th p i n m t n i n t mpl ha mon c b c the c n t g r d i n t nfin te n l gth and th pi t n t a ls m th n half t tr k wh n the ankp t rn 90 f m firing d ad cente Th s di t t n of th tru harm n mot on du t the o- ll d ngul ty a of th onnect ng od

$$= \frac{s}{2l} \qquad (3)$$

h r i the c a k rad the t oke a d l the ect ng od le gth ll i n h

Rec p o t ng e ti f a t n l with the yl nd ts d may b id red a e mb a ti f a pr mary f rce—th t e h rmon c f e f m Eq (2)—o e ll t n t th ame frequ cy a th h ft pm a d nd ry force c l l ting at tw th f q n y h ing a al e of Fa wh h i dded t the p mary t fi g d d c t r d bt a i d f m t t n r d ad ce t r l e ft the a i fi t b t p dly d m i h g seri of eve harm n cs at 4 6 8 t m nk h ft p ed b t b the d h rmoni th y t so mall th t they m ge ally b neg lected Th s f r ecting d w th the er ge g la ty f the 1959 t m b l e g whe a = 0.269 the nert a f ce used by p t n t fi ng d d e t t bo t l 7 t mes the pu bar m n f and t i d d nt r t 0.73 t m l g

Wh tw pi to s act on ne c a kp n with the l d 90 V r me t m t m in F g 11 th res lta t p m ry f e i ra d l d f con te t m g n t d a d tates a u d th e ank h ft w th th kp Th f t m y be ompen ted f by a dd ti n t th we ght q i d t ing kp d t a soc ted m es Th ult a t f the co dary f r f the tw ton 1.41 times l rg s for n cyli der a d ecip o- cat a ho zont l plane th ough the r nk haft at twi e cr nkshaft spe d

I n i w th oppo ed ylind s if the two o n ting r d ope te th am rankp n a in Fig 11b the pr ma y f rc a e added and a tw ce a great as for o t but the nd ry fo c s c n l If th p t ns pe te on tw crank 180 apart a n Fig 11 all rec pro at ng fo c re bal n ed H w a th y will be n d ff re t pl n o k g e uple w ll d elop le s c mpe sated by an opp s g couple f om an oth r pa of cyl nde D uble ppo d pi to p i p r t ng a ngle ylind n tw cr nk haft s in F 11d (with a r s shaft t mai t i ynch m) e i p fe t balan e for pri mary and econd ry procat g for es as w ll a fo r t ti g ma es a d to que ea tio s

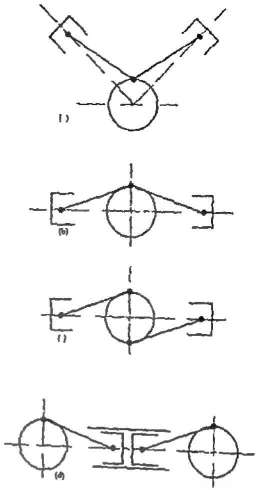
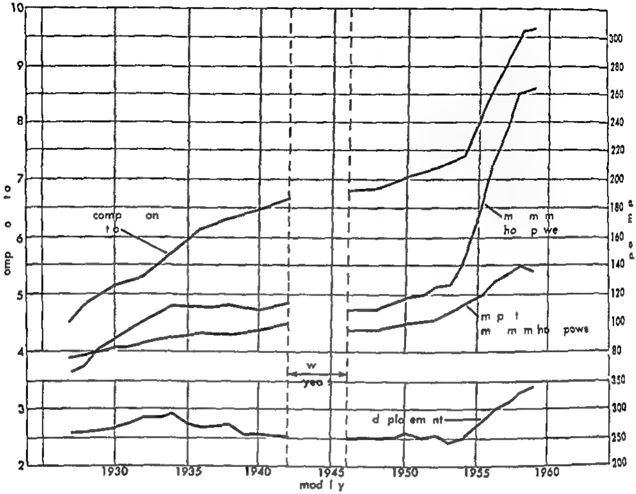
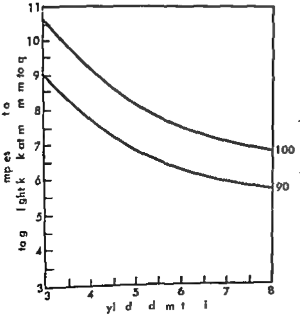


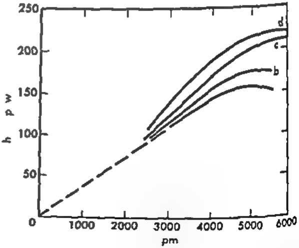
Fig 11 A g m ts f two cyl d rs (a) 90 V f m f w th c t g d p t g n th m kp n (b) opp ed cyl d w th n e t g od p t g th me c k p n (c) pp ed cyl d rs w th p t n p at g n k p 180 ap rt (d) d uble-opp ed p t th sam cyl d but pe t g sepa t k h ft



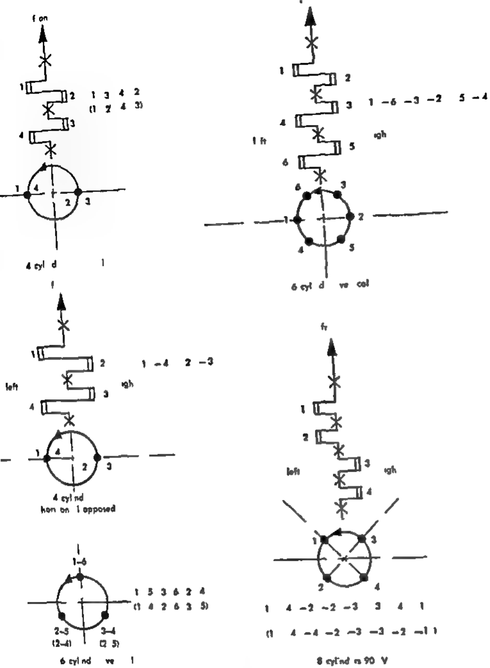
Fg 8 Trend n compres on rat o mea effect v pressu e and power of ave age Un ted St te a tomo bile g nes



Fg 9 Rel tion between cyl nde d ameter a d l m t ng compre s o r t o for n g es of s m la des g w th 90- n d 100-octane gasol s



Fg 10 I c a e I the p k pow f a s -cyl nd ng (210 in d plac m nt) by c n e reduc t o i the i ta c t flow th ugh it C rve a pow d loped by o g l e g e w th two 1½ ca b t u b h ghe al e l ft v l s nd d l e hau t sy t m cu e c la ger v l smoother alve po t a d two 2 in a b to s c rv d th e dou bl b l a bu et



12 Typ l cyl d m g m ll d fi g d rs

i t pe lt h th d d t g how f
i g m e t m t e h rm l m f ld
npe t nles the w t pply f m th yl
l h d h rt ted th gh th m f ld
k t by t bl wat th rm t t d g
m p

O f th d tage f th V 8 g e t the
ll t t k m f ld d g perm tted by th
ent lly loc t d l t w th b t m ll d ff
es th l gth f th p ag betw th
b t nd h yl der d q l mbe
f ght gl be d h t typ l t t ke

m f ld t g d l carb ret r (Fig 14) With the u al fir g o der h wn in Fig 12, the firing interval for e ch f the l wer b che (sh wn d tt d) ev ly p ed 360 k h ft degrees part, b t fo h f the pp b he two cyl d fi 180 d then 540 p rt

Ic g Be g l e ha d ble l te t h t f po izat t l we the a t mpe atu e a it evapo t s. Th s tru even at the low t m p r t es whe e ly mall part f it i por zed ll ther f p bl f m t e wh h may be c rr d by th a to f ez und ert c ndi

In the conventional four cylinder in line engines with crankpins in the same plane the primary reciprocating forces of the two inner pistons (2 and 3) cancel those of the two outer pistons (1 and 4) but the secondary forces from all pistons are added They are thus equivalent to the force resulting from a weight about $4a$ times the weight of one piston and its share of the connecting rod oscillating parallel to the piston movement having the same stroke but moving at twice the frequency A large a for this type of engine is advantageous Where the four cylinders are arranged alternately on each side of a similar crank shaft and in the same plane both primary and secondary forces are in balance Six cylinders in line also balance both primary and secondary forces

Early eight cylinder 90 engines with four crank pins in the same plane like those of the early four cylinder engine had unbalanced horizontal secondary forces acting through the crankshafts which were four times as large as those from one pair of cylinders

In 1927 Cadillac introduced a crank arrangement for its V-8 engine with the crankpins in two planes 90 apart Staggering the 1 and 2 crankpins 90 from each other equalizes secondary forces but the forces are in different plane The couple thus introduced is cancelled by an opposite couple from the pistons operating on crank pins 3 and 4 This arrangement of crankpins is now universally used on V-8 engines

Torsion dampers In addition to vibrational forces from rotating and reciprocating masses vibration may develop in an engine from torsional resonance of the crank shaft at various critical speed The longer the shaft for given bearing diameter the lower the speeds at which the vibration may develop Such vibrations are dampened on most six and eight-cylinder engines by a vibration damper which is similar to a small flywheel on the crank shaft at the end opposite to the main flywheel but coupled to the shaft only through rubber so arranged as to reduce the torsional resonances Such vibration dampers are usually combined with the pulley driving the cooling fan and generator *See* MECHANICAL VIBRATION

Even though the majority of American automobile engines are now dynamically balanced it has been general practice for several years to mount them in the chassis frame on rubber block This reduces the transmission of the small amplitude high frequency vibrations in torque reaction as well as small unbalance of reciprocating part in individual cylinder so that a low noise level is developed in the car from the operation of the engine

Firing order Cylinder arrangements are generally selected for even firing intervals and torque impulses as well as for balance As a result the cylinder arrangements and firing order shown in Fig 12 may be found in automobile use It is generally customary to identify cylinder banks as left or right as seen from the driver s seat and to number the crankpins from front to rear Manufacturers do not agree on methods of numbering individual cylinders of V type engines However the arrangements and firing orders shown are in general use with the addition in parentheses of alternate arrangements only occasionally used.

Intake manifolds Intake manifolds for multicylinder engines should meet several requirements for the satisfactory performance of spark ignition engines They should (1) distribute fuel equally to all cylinders at temperatures where unvaporized fuel is present, as when starting a cold engine or during the warm up period (2) supply sufficient heat to vaporize the liquid fuel from the carburetor as soon after starting as possible (3) distribute the vaporized fuel air mixture evenly to all cylinders during normal operation and at low speeds (4) offer minimum restriction to the mixture flow at high power and (5) provide equal ram or dynamic boost to volumetric efficiency of all cylinders at some desired part of the engine speed range

Experience shows that the passages between the carburetor and each cylinder should be nearly equal in length with the same number of right angle bends and that no cylinder should be siamesed with another at the end of a leg of the manifold, particularly if the firing intervals for these cylinder are uneven Passage length affects the amount of boost in volumetric efficiency or mep and the speed at which it peaks (Fig 13)

For the warming up period with liquid fuel present rectangular sections are desirable to impede spiraling of liquid fuel along the wall and right angle bends should be sharp at least at their inner corner so as to throw the liquid flowing along the inner wall back into the air stream.

Manifold heat Intake manifold of most American automobile engines are heated to the temperature required to vaporize the fuel from the carburetor (120–140 F) by exhaust gas passing through suitable passages in the manifold casting particularly at the first T beyond the carburetor where the liquid fuel impinges before turning to side branches To speed the warm up process thermostatically operated valves are generally placed in the engine exhaust system so as to force most of the exhaust gases through the intake manifold heater passages when the engine is cold After the intake manifold has reached the desired temperature such valves are intended to open and permit only the necessary small portion of exhaust gases to continue passing through the heater This is an important feature for too much heat causes a loss of engine power and aggravate the tendency for the engine toward knock and vapor lock

On some engines the intake manifold are heated by water jacket taking hot water from the engine cooling system This gives uniform heating over a wide range of operating conditions without danger of the overheating that might result from exhaust gas heat if the thermostatic exhaust valve should

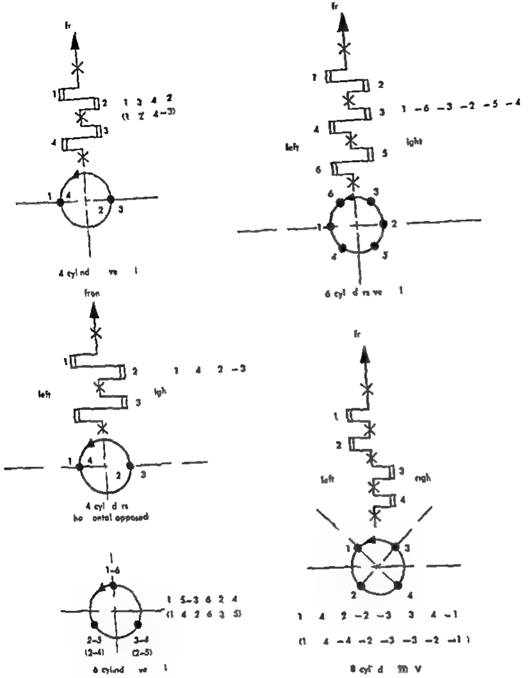


Fig 12 Typ l cyl d rra g m ts d fi g d

f l t re It ha th d s d ant ge h wev r of g m t m t re h no mal m fold t mpe t r l th wat pply f m th cyl d h d hort u ted th gh th m f ld t k t by t bl w t the m st t d r ng w rm p

O f th d t g f the V-8 e g th ll nt t k m f ld d gn p rm tted by th entr lly loc ted b r t w th b t mall d ff es th l ngths f th p g betwee the a b t d h yl d d an qu l mbe t ght gl be d s h a typ c l ntake

m n f ld us g du l a bu et r (F g 14) W th the ual fi g d shown Fig 12 the fi ng i t rvals fo each of the low bra hes (h w d tted) e e ly p ed 360 cra k haft degrees ap rt b t for e h f the pp r b an h s tw cylin de fire 180 d then 540 part

Icı g Be au e g l ha ns d bl l te t k t of po t t l wers the a t mp t it e t Th s true n at th l w t m tu wh e nly mall part f p z d It is th ef e p bl f m i t wh ch m y be e ed by th a r t fr eze u de rt n cond

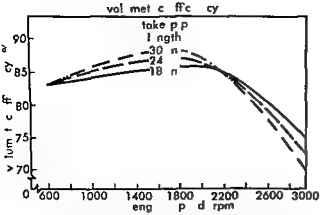


Fig 13 Effect of intake pipe length on the volumetric efficiency of a single cylinder engine at different engine speeds

tions Ice is most likely to form when the atmosphere is almost saturated with moisture at temperatures slightly above freezing and up to about 40 F When ice forms around or near the throttle it can seriously interfere with the operation of an engine For this reason small passages have been provided on some engines for jacket water or exhaust gas from the heating supply for the intake manifold to warm at least the flange of the carburetor Here again too much heat would produce vapor lock and this would interfere with normal fuel metering

Typical American automobile engine The typical automobile engine as manufactured in the United States during 1959 was an eight cylinder 90 V with overhead valves such as shown in Fig 15 The cylinder blocks and upper crankcase are cast in one piece The structure has sufficient rigidity to permit high speeds (4400–5000 rpm at maximum power) without serious deflections Crankshaft stiffness is aided by a main bearing between each pair of opposing cylinders which have their connecting rods staggered side by side on the same crankpin

The V arrangement makes possible efficient intake manifold design with symmetrical and almost equal passages to each cylinder from a centrally located down draft carburetor It is short and low important characteristics for the styling of the

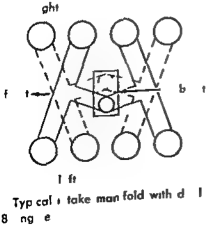


Fig 14 Typical intake manifold with d l carb tor on a V 8 engine

cars in which it is used It is water cooled under pressure limited to 7–14 psi by a spring loaded radiator cap and it has water jackets completely surrounding each cylinder for the full length of the cylinder barrels Valves are operated by a single camshaft in the V which is driven by a silent chain. Over 70% of the engines quiet the valve action by hydraulic lifters (*see* HYDRAULIC VALVE LIFTER) Almost as many engine designs provide means of rotating at least the exhaust valves during engine operation and some rotate the intake valves also. This distributes wear and improves valve life It is standard practice to provide two narrow compression and one oil scraper ring on each piston above the wrist pin About half the designs lock the wrist pin in the connecting rod the remainder leave the pin free to rotate All compression rings are of cast iron about 0 078 in wide and have wear resisting coatings Top rings are generally chrome

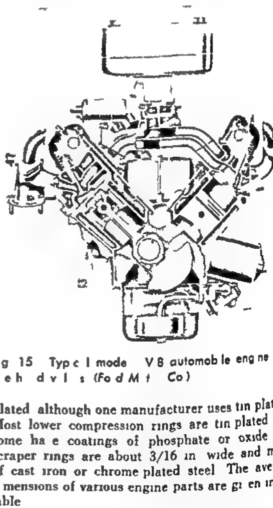


Fig 15 Typical model V 8 automobile engine with overhead valves (Ford Motor Co)

plated although one manufacturer uses tin plating Most lower compression rings are tin plated some have coatings of phosphate or oxide scraper rings are about 3/16 in wide and made of cast iron or chrome plated steel The average dimensions of various engine parts are given in the table

FUEL CONSUMPTION AND SUPERCHARGING

Fuel consumption at loads throughout the operating range of an engine provide insight into such characteristics as friction loss within the engine Volumetric efficiency of an engine can be increased by use of supercharging

Part load fuel economy When the fuel consumption of a spark ignition engine at a given fuel air ratio is plotted against brake horsepower

ag engi d men ion (I i ches)
1959 automob l s

	4 0
Cyl d bore	3 46
Strok	6 41
Co ectu g rod l gth	0 69
R t f cra k d t l gth	8
Co ectu g rod b g-e d be ri g d m t	0 81
Co ectu g rod b g-e d bearı g w dth	1 9
Co ect g rod b g-e d bearı g	0 99
Wr t p d m t	[illegible]
M be g d m t	0 89
M be ri g l gth	31
M be ıng	1 90
I tak l h d d m t	1 56
Exh ust l h d d m t	

tr ight l ne m y ge rally be dr wn th ough the te t p nts at g n peed as h wn n Fı 16 pr ded that th test r run w th opt mum pa k d a ces. S h l e r mila to the Will ns lines l g u d f r the ste m on umpt o of t am en g nes

Fo p act cal p p s th l n s at r o s peed m y be c s d r d p r ll l r a w d fuel ra g f pe d Wh n ext p lat d to z r fuel c n mpt the n gat pow r ad gs may be co de d a th fr t o p we abso b d t the re p nd g peeds. O ch o d ate h e rad ti g f m th ıg p e e t c n t nt r t o f f l c n umed t p wer developed nd th r f r c tant pecific fu l c n umptı n (f) Seve al ch l e a e ı d c t d al ı Fig 16 f m wh ch th f at r l ads m y b d d r ctly wh e th y c the p rf rmance l nes at the ar ous p ed

S mil r pl ts of even gr ater ut l ty may b d d c ted ho epowe ba s s h ben d e Fig 17 f r the me dat F ma y g es s gl pe fo ma l n m y be d wn th gh all te t p ts t [illegible] en f el ai r ti [illegible] a c id rabl a ge f peed When t p l t d the p f rm e l [illegible] es th gh th rıgı t doe f the [illegible] h w F g 17 th ındı ted f a d thermal effi e y of the g rema c n

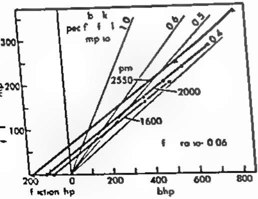
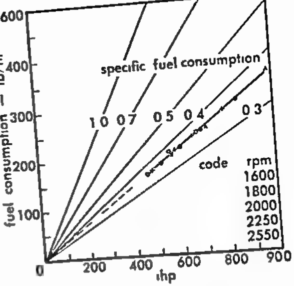


Fig 16 F l mptı f gl t p rt load pl d typıc l Wıll l g t b k h rse-pow Do w t k w th pt m m p k d d w h f l-a t dı t d t h t t p t



Fg 17 The d t f F g 16 pl tt d ag i t i d t d h p w by wh h th d ff s f p ed a t l d

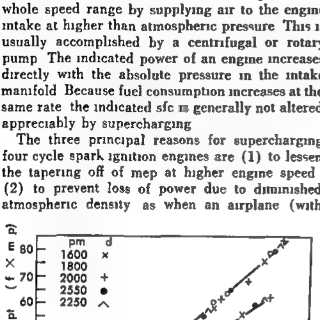
sta t o er the l d rang e ed Frequently a pe form nc l ne for n eng e pa es a l ttle to the l ft of th rıgin beca of nditon cau ıng a d c ea ın th rmal effic en y as the load ı e d ced uch s sufficie t turbulenc r t o low a man fold l ıty For a mo e complete pıctu e of the f el c sumptio perfo ma ce of an e gı e s mil r plot m y be made n an mep b ıs Whe th d s and b th fuel c nsumptı n a d ho e powe a d ıded by the g ne factor whı h con ertsh ep we to mep the sl pe nd nat [illegible] f the f el p rf rm c lın r ma unch ged The fuel s mpt on c l th n b c mes q val nt to the p d t f m p a d sfc S h plot may be on the ba f e th ınd c t d m p (mep) b ak m p (bm p) Figu [illegible] sh ws th me data F g 16 d 17 plotted an mep ba ı for two d ffere t fuel r tı s

The f l umption perf rm n of d e el g s t part load may b hown on m lar ba [illegible] b t th plot ho ld not b exp ted t be t ght b ca th ffect fuel r at aries w th lo d Th s ıll trated F g 19 It ı haracte tıc of m t d e l ngın that th c rv t e of th plot g e lly flatt t at l w loads that ıt be come t mpt g t e trap l t ıt to ze fuel c n mptıo If th the mal ffic e cy mp [illegible] w th red ct f l d ıt would theory f th l cal d esel y l b cau e f th educed cut ff th ı te c pt w ll be t the ght f th orıgın when pl tt d n a ımep b If pl tted [illegible] bm p b ıt wo ld be t th r ght f th tru mea u ed frıct n m p It th f n t f t t m t th f ıctıo of a d esel engine by th method l n d t m urements are a a lable d r gh pp m t n t f ctory Alth gh the e f el con umptı n pe f rm e plot f

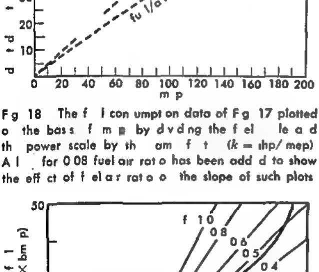
considerable utility for recording such data for an engine the fact that they are curved requires at least three or even more points to fix their location on the plot

Supercharging spark engines Volumetric efficiency and thus the mep of a four stroke spark ignition engine may be increased over a part or the whole speed range by supplying air to the engine intake at higher than atmospheric pressure This is usually accomplished by a centrifugal or rotary pump The indicated power of an engine increases directly with the absolute pressure in the intake manifold Because fuel consumption increases at the same rate the indicated sfc is generally not altered appreciably by supercharging

The three principal reasons for supercharging four cycle spark ignition engines are (1) to lessen the tapering off of mep at higher engine speed (2) to prevent loss of power due to diminished atmospheric density as when an airplane (with



Fg 18 The f l con umpt on data of F g 17 plotted o the bas s f m p by d v d ng the f el le a d th power scale by th am f t (k = ihp/ mep) A l for 0 08 fuel air rat o has been add d to show the eff ct of f el a r rat o o the slope of such plots



Fg 19 F el co s mpt n of a d es l e g at part loads showi g th urvature typ c l of h engi e on the e c o d *ates d* e to Inc ea ng ffect s of f el-a r rat as the l ads are nc ea d

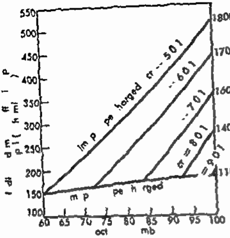
piston engines) climbs to high altitudes and (3) to develop more torque at all speeds These will be discussed in greater detail

In a normal engine characteristic torque rises a speed increases but falls off at higher speeds because of the throttling effects of such parts of the fuel intake system as valves and carburetors If a supercharger is installed so as to maintain the volumetric efficiency at the higher speed without increasing it in the middle speed range peak horsepower can be increased with little if any increase in octane requirement

The rapid fall of atmospheric pressure at increased altitudes causes a corresponding decrease in the power of unsupercharged piston type aircraft engines For example at 20 000 ft the air density and thus the absolute manifold pressure and indicated torque of an aircraft engine would be only about half as great as at sea level The useful power developed would be still less because of the friction and other mechanical power losses which are not affected appreciably by volumetric efficiency By the use of superchargers which are usually of the centrifugal type sea level air density may be maintained in the intake manifold up to considerable altitudes Some aircraft engines drive these supercharger through gearing which may be changed in flight from about 6 5 to 8 5 times engine speed The speed change avoids oversupercharging at medium altitudes with corresponding power loss. Supercharged aircraft engines must be throttled at sea level to avoid damage from detonation or excessive overheating caused by the high mep which would otherwise be developed *See* SUPERCHARGER

Normally an engine is designed with the highest compression ratio allowable without knock from the fuel expected to be used This is desirable for the highest attainable mep and fuel economy from an atmospheric air supply Any increase in the volumetric efficiency of such an engine would cause it to knock unless a fuel of higher octane number were used or the compression ratio were lowered When the compression ratio is lowered the knock limited mep may be raised appreciably by supercharging but at the expen e of lowered thermal efficiency There are engine uses where power is more important than fuel economy and supercharging becomes a solution The principle involved is illustrated in Fig 20 for a given engine With no supercharge this engine when using 93 octane fuel developed an imep of 180 psi at the borderline of knock at 8 1 compression ratio If the compression ratio were lowered to 7 1 the mep could be raised by supercharging along the 7 1 curve to 275 imep before it would be kn ck limited by the same fuel With a 5 1 ompres ion ratio it c uld be rai ed to 435 imep Thu the imep cou ld be rai ed until the cylinder became thermally limited by the temperatures of critical parts particularly of the piston head

Supercharged diesel engines Combusti n in a four str ke die el engine is materially improved by



Fg 20 R l t h p b twe omp t o d k k l mated m p f g mb b to ed by pe ha g g l bo t ry g e

upe cha g In f ct f els wh h would sm ke l dly and m sfi e t l w load w ll b n otherwise t sfacto ly w th s per ha g g The imep s d rectly with th up r harge pre ure nt l it s l m ted by th rate f h at flow f m the met l p rts surro nd ng the mb stion hamber and th r lt g tempe atu e A pra tical appl c tion of th l mit t on wa mad n a loc moti built by th Br t h Ra lways whe e th p wers and thus the h t dev loped we held r a n bly const nt ove a id rabl peed rang by d ng the u pe ha g r t n tant peed by it wn eng I th w v th pe ha ge pr r a ied n rsely with th pe d f th m t e g The c rre p d g t rqu r se at ed d p ed d p n ed with m h g ar hifting wh h would ha been re qui d du g a l r tu n w th a con nt l en g n

Wh s pe h g f the th cent if g l r po t e d pla m nt typ are dr en me h n ally by the eng the powe eq ed b mes n addi t l l t the ng n tput Exp n e h w th t th r d g e of upe h rg f y eng ne h h dev l p ma m m effi e cy too high a pe h b b m e pow r th uper h g th n d l y th eng ne pe lly t l w l ads A ther m of d ng the up r h rg wh h b m g q t gen l by h t t b wh h r m f th ergy th t ld th w be wa ted n the ng n ex h t Th ma be e mpl hed w th m ll n f b k p es r th t l ttle p w l st b th eng Th type f d es Its n pp ev bl r ffi ie v t lo d h gh gh t dev l p th ece ary xh t pr pe l two-cy l d esel g n requ m m f cu t ng th ul g th exh u t d t t ld up yl d p e t the tart f th mp es irok nd i used o a f w larg M t med ma d l rge two-cy l l sel en es ll l pped w th bl w to a ng

th cylinder after th w rking strokes and to upply the air requ red for the ub eque t cycles The e blowe s n cont a t to supe charge s do not build up app ciable p essu e n the cylinder at the tart f c mpre i n If the capac ty f such a blower is gr te tha the engi di plac ment it will scav nge th cyl der f practic lly all exhaust prod uct even to the extent of blow ng some a r o t thro gh the exhau t ports Such bl wers l ke super charger may be mech n cally dr en by the engine or by exh ust t bi es [N M]

Bibl g aphy W H Crou e *Automotive En gin s* d ed 1959 W H Crou *Automotive Mech n cs* 4th ed 1960 L C Lichty *Internal Combusti E g s* 6th ed 1951 H R Rica do *The High Speed Int r al Combustion E gi* 1931 C F T yl r and E S Taylor *The Internal Com bustion Engine* 1948

Internal energy

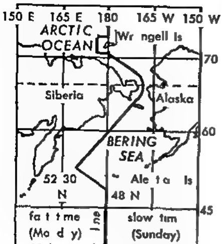
A ha acteri tic pr perty f the tate of a thermodynam c syst m ntroduced n the fi st law of ther modynami s For a static closed sy tem (no bulk moti n n transfe of matter acr s its b unda r es) the hang ΔE n i te n l energy for a p oc es m q al to the he t Q ab o b d by the system f m t u r u di g m n s th work w d ne by th y t m on its ur ound ngs O ly a change in nternal en gy ca be mea ured n t its alue f r ny ingl st t For a g i pr ce s the ch nge n ntern l ene gy i fix d by the in tial nd final states nd is i d pendent of th path by which the cha ge n tate s ac mpl hed

Th ternal e ergy in lud s the ntrin ic en e gi s of the ind idual mol cule f which the sy t m i mpo d a d ontributio s from the n tera ti n am ng them It does not includ e ntri b t on f om the potent al e e gy o kinetic en ergy of the sy tem a a whole th changes mu t b a counted f r expl c tly n the t e tm nt of fl w ystem Becau e t mor c n n ent to use a an ndepe d nt i bl (the p es ure P fo the sys tem nstead of its l me V) th wo king equa ti ns f pra t l thermodynam c a us ally writ t n n t rms f uch f ncti o s as the enthalpy $H = E + PV$ nste d of the int rnal energy itself Se ENTHALPY THERMODYNAMICS (CHEMICAL)

[P B]

International Date Line

The 180 me dian where ach day offic lly b gi a d end A a pe on tra ls e stwa d gai t the appa e t m eme t of the un he g ns l ho for eve y 15 f l ng tud a h t a el we tward he l e t me at the m ate Two pe ple tart ng f m y m d n a d trav l ng r und the world in opp te d ection would ha the s m time when th y me t, but wo ld be 1 day ap rt date If th w e n nternati n l agreement a to whe h d y h ld b gin nd e d th uld be y numb r of pl s de gnated To l mi



Th Intern t onal Date L

Conference in 1884 designated the 180 meridian as the location for the beginning of each day Thus when a traveler goes west across the line he loses a day if it is Monday to the east it will be Tuesday immediately as he crosses the International Date Line In traveling eastward he gains a day if it is Monday to the west of the line it will be Sunday immediately after he cros es the line

An interesting example can be taken from conditions now nearly attainable with jet aircraft If one could board such a plane say at noon in Washington D C and fly westward at that latitude around the world to return in 24 hours the rate would match the rotation of the earth Although constantly under the noontime sun this traveler would need to adjust his calendar one day ahead upon crossing the International Date Line because he would arri e in Washington at noon 24 hours after embarking Thus his calendar day would agree with that of the Wa hingtonians

The 180 meridian is ideal for serving a th e International Date Line It is exactly halfway arou d the world from the zero or Greenwich meridian from which all longitude is reckoned It al o fall almo t in the center of the large t ocean consequently there is the least amount of inconvenience as regards population centers A few deviations in the alinement have been made such as swinging the line east around Siberia to keep that area all in the same day and westward around the Aleutian I lands so that they will be within the ame day a the rest of Alaska Other minor variations for the same purpose have been made near the Fiji I lands in the South Pacific *See* GEOGRAPHY MATHEMATICAL [V H E]

Interplanetary propulsion

Powered flight between planets The sy tems u ed for interplanetary propulsion must provide the acceleration to propel a flight vehicle and to maneu ver it along its trajectory High acceleration is desirable for near space flights and chemical rockets seem most appropriate Moderate acceleration is adequate for trips to the inner part of the olar system Low acceleration during the long times for flights to planets beyond Mars will produce acceptable velocities for such flights electrical propulsion systems eem uniquely qualified In add t on to the midcourse propulsion systems the vehicl or its detachable booster may use other propul i n means for launching landing and operating in the regions of strong planetary gravitational fields (*see* ROCKET STAGING)

Engine types Several basic propul ion techniques have been considered for interplanetary propulsion Two are rockets in the strict sen e that they carry and heat their own fuel and expul i e material (*see* ROCKET) These are the chemical rocket and the nuclear rocket The other techniques rely on solar energy or carry their own eparate energy source they are the olar heating rocket photon propulsor and electrical propul or

Chemical rocket The nature of the propellant whether solid or liquid provides the ba is for classifying chemical rockets (*see* PROPELLANT) Both types convert chemical energy into thermal energy of a working fluid by combustion and convert the thermal energy into kinetic energy in a nozzle expelling the working fluid at high velocity to pro ide forward thrust *See* ROCKET ENGINE

A s lid propellant rocket once ignited normally burns until all its fuel is consumed The shutting down and restarting of a liquid propellant rocket is feasible but requires special techniques A low pre sure monopr pellant rocket is more ea ily restarted but de elops lower performance (*see* SPECIFIC IMPULSE) A monopropellant rocket develop a specific impulse f 200–225 ec compared with a theoretical lim t of 440 ec for a high energy bipropellant

Nucl a pr pulsi n Three type of nuclear r cket are under study In the fi sion type uranium in a sol d reactor he t a w rking fluid u ually hydrogen The wo king fl i d then accelerates thro gh a nozzle a s of rockets

The u e of wo king flu d of low mol cular we ght nabl thus ro ket t p odu e a high r sp c fi mp l than a chemic l r ck t in wh h tle work g fl d a m xture of the products of c mbus- H wev r th t mperature lim t of 4000–5000 F imp ed by exi t ng re t r and nozzle mater als pre ent the full p tent al ti s of the nucl r r ket from bei g r al z d at p ent *See* NUCLEAR AIRCRAFT PROPUL IO NUCLEAR ROCKET

The h gh int n ty ne tron d gamma rad ation fr m th r acto heat adjacent h rdwa e n that t mu t be ol d S iti e equ pment and human er w can be h lded with relat ase by heavy shadow sh elds compl te enclo re is unn ces ary n nterplan tary pace f r the no a r to scatter the rad at n Alter t vely act r and us t ve p load ca b widely s parated w th con iderable a ng n w ght but w th th introdu t on f addi t nal des gn probl ms lso act r and pr pul ion flow ontr l are mpl x and intricately related

Fu n ea t ons may s m d y llow the development of a c nd type f u l r cket Th y a d nde t able by p odu t and uld relea th rgy d r tl to the working flu d Howe er lu o techniq r t t be developed

The th d typ f n clea r cket now being n v t gated u e n gy fr m dio ctiv d cay lpha beta o g mm rad at o all three *Alph a d f ta parti l a adily nve ted to* h at G mm parti les are h rmf l to electr ic q pm t d h man be and r qu re h eld g l ot pe f l i pen i t produc ts l fe is l mited a d a p op il ive y tem u ing top *would* r quire pe i l ol ng pr n l e aus h at evol ed by th fuel t ll t m s S h n ng would be s table prima ily f l w thrust E n so with hyd g n as tle w rk g fl id and uffi tly high temperat r s h v t m can be xpected to d l p a spe ifi mp l e of 600 00 sec

Becau f th potent alit of thes clea p pul on m thods, they a e be ng studied Th r t hn cal dev l pment aw ts furth t fic kn wl dg

El ctri al p p l i The xp ll nt mat al n be g n high loc t b ele tr c l mean Th ee ba typ f electr l p opul n are *re h t g n j ti a d m gnet pla m a el r* n Ar h ati u e l tr l he ting f the w k g fl d 15– 0% of th lectri l ene gy ap pe ng d ectly a k t energ in th o ki g flu d By g th pr p llant ge er t e cool ant 50–60% f th lectric l e gy be co ted t k n t e rgy At p es nt elect od r n l m t l f

In i d m g t pla m p p l the rk g fl i l r d l et i lly i t ad of th r *mod* mi lly l on v on f th i rocket, ta t f tw d m l m t r l i ures the p pella t hi h i th n a el r ted in a l ctro- tat fi ld in es f 10 000 olt Specific im pul es f over 60 000 e appear feasible Electrons are disch rged near the i n j t t neutral ze it The propellant is preferably a material of h gh atomic we ght *See* ION PROPULSION

In a magn t pla ma ro ket a fluid of ions and electron (the total fluid b ing electrically neutral and called a pla ma) is a *cele ated by reaction* w th a changing magnetic field or by interaction of an electr c cu rent and a teady mag et c f eld (see ELECTROMAGNETIC PROPUL ION) Th pla ma can be restra ned magnetically s that as heat the ngine w ll are prot ted With a fluid f low at mic weight such s hyd ogen a cel rated by a changing m gn tic field a specific impul e in ex s of 15 000 er s pos ible It may be feasible to transfer o er 90% of the magnetic nergy into k net c e e gy by thi method *in its pr ent f rm* the el ctr cal equipme t is he vy nd complex S e MAGNETOGASDYNAMICS

A teady th u t can be pr du ed by pa ng an ele t ic urrent thr gh th plasma orthogonally to the fl w and t a steady magneti field In this w y a pecific impulse of 1000–1500 c seems possible

The ele t ical power for prop l ion ould be duced va usly (Fig 1) The r latively fixed c t cal mass of n clear fis on react s, and to a les er extent the hea v sh elds for i tope and r a t s do not i crea e proporti n tely with p wer output Th r f r the extr ct n of high el ctric p wer f om the e ng s may improve the o er all thru t weight rati

Waste h t fr m the ng nes must be *r jected* ad th eje t n temper tur d t m nes the th r m dynamic effic nc (*see* C RNOT CYCLE) Th we ght of adi to s f heat r je t on m t be i *cl ded in* the eng ne weight E e so th efficiency of therm dynam c tu bogene at rs today s much gre te than that of pre ent de elopment l d ect thermoelect ic en rgy conve th t th more c n e ti al m thod appe r to be p f rabl for high power r qu r m nts

S l h ting The wo kin flu d f a rocket c n b h ated by olar rad ti n t temperatur of

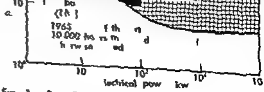


Fig 1 Sp f w ghts f l l ct l pow
U l f th A o/Sp c S

1000–2000 F (*see* SOLAR ENGINE) At the Earth s distance from the Sun a reflector area of 8 ft²/kw is needed if 100% of the captured radiation is converted to power (*see* SOLAR CONSTANT) Considering all the losses probable in uch a heater from accuracy with which the reflector is pointed at the Sun to efficiency of a solar boiler the reflector area may need to be 80 ft²/kw At Mars distance from the Sun the reflector would need to be 200 ft /kw Just how such a reflector for a high power ystem would be transported into space remains to be determined

Photon propulsion The radiation pressure of the photons from the Sun is about 10 lb/ft at the Earth s distance The total pres ure due to action and reaction on a perfectly reflecting surface w uld be twice this value Although force is limited by being directed only away from the Sun olar ail ing can provide low thrusts and attitude control turning a space hip completely around in a few hours Because no working fluid is carried in the vehicle this type of pr pul ion i ec nomical in weight

For the vehicle to carry its own light ource a photon rocket of adequate thrust would neces itate energies far beyond pre ent capabilitie Becau e the photon velocity is the speed of light relativistic effects mu t be considered Also the need for cooling of mirrors precludes a practical device u ing pre ent technology

Performance evaluation Each space flight requires particular engine performance Thus there is no best engine but there are engine better suited for some mis ions than for others The table pre ent data for the principal types f engine Figure 2 shows the relation of acceleration (which is al o the thru t weight ratio f the vehicle) to pecific impulse (or exhau t velocity) and to pecific power (which is here the ratio of kinetic energy in the jet per unit time t the over all weight of the vehicle including its source of energy)

Chemical and nuclear rockets provide high thru t for short duration The other engines perate for long durations at low thru t F r sh rt trip rapid acceleration is de iral le for long trip low acceleration may produce usable over all flight time For such service a interplanetary freight the h h specific impul e of the electrical units would allow a vehicle so powered to carry a heavier payl ad than if dri en by a chemical rocket

Ranges of specific impulse thrust to weight ratio and duration

Sy t m	Sp f i	Tl t to w ght t o	Typ l l t
Cl m l	00–4 0	10 ²–10	M tes (l gl t) Ml (l w tl t)
F	00–1 100	10 10	S l m l y t m
Isot p l y	100– 00	10 10	D y
A l t g	400– 000	10 ⁴–10	D y
M g to pl m	5 000– 000	10 10	W k
I	5 000–60 000	10 10	M t
Sol h t g	100–700	10 ²–10	D y

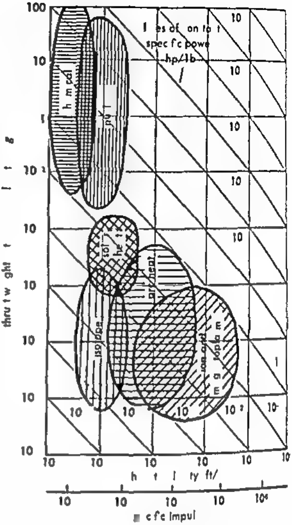


Fig 2 Regions of acceleratio s and spec fc po er for var o s rocket (J rnal of the Aero/Sp ce Sc enc s)

Trajectory requirements The even ba ic interplanetary maneuvers are pre ented in Fig 3 t gether with the engines suital le f r each The interplanetary flight really starts from a satellite orbit bey nd the greater part of the Earth s atmo phere It is a umed that the energy neces ary to lift a ehicle off the ground and to put it into a atellite orbit i pr vided by eparated rocket b ter e hi le To minimize the energy nece ary to o er me the relati ely trong gravitational field the thru t h ul l be applied during a brief period Chemi al and nuclear rocket are theref re the nly suital le engines for this maneuver Inter planetary propulsion need supply only the energy to accelerate from orbital vel city and for the other interplanetary maneuvers

Interplanetary orbit transfer is the next maneu ver Ba ically it is the overcoming of the gra ita ti nal f ld of the Sun and the correcting f r differences in tangential el citie of the launching

m uv	E ⊂	⊂						
sc pe f m bt	○	)		○	○	○	)	○
pl ry tr f	○	○	○	○	○	○	○	○
h g f pl	○	○	○	○	○	○	○	○
t	○	○	○	○	○	○	○	○
ect ry ectio	○	○	○	○	○	○	○	●
g pproa h	○	○	○	○	○	○	○	●
pt	○	○	○	○	○	○	○	●

○ t bl ◐ pt bl ● d bl

I g I d ect I d

Fg 3 S t bl ty of p opul yst m t dff t I t pl t ry m U I f th A /Sp S e)

a d the ta g t pl net Th d al zed minim m en gy att i ed whe fly g the t j ctory of a so-alled Hohma n ell p t t ge t at t phe- l to th bt f the o t r pl et a d t it p h I t the bit f the i e pl et nd h the Su t t p me f A p r t ppl at n f th t may b u ee ry f r tl m n u e n if a f te tr n fe rb t eq g great en gy f ll wed b u the e gy may b p- pl d t tl me tim a th ape man r S Ellipse

Th bt f e h pl net tilted t a d ffe nt b t m ll a gle t th pla f the ecl pt c De-pe d ng pon the po t f la n h n d th targ t pl et d pon the reg n f the flight tr ject ry wh h th ehi l h ges from the pl f the bt f pla t t the pl ne f th bt f th th n e rgy pp i ble gy may be q ed

h l r t t n m y n ed tr I fo h p t a g t I li rv t d m m t r f ec t g la e gv O e way t ll thi tr I s t I w thr t p o- p I n y tem r y I nt I f g t mpo t n e A multiple- zle m opr p lla t t m a y f sol r d t p es fl t appea t b d ll t d f r th m n u

T a t rv rrect e n I m d l wly The en gy r q ed f r h r t n d pe d p n th r h ul de gn f t r espec lly th err s igat dev es gu d a d ntr l a d pon th pl t a d th e u a y f th m p of the sol y t m

th h I ppr a hes th ta g t gl t h g i loc ty m y be eeded t mat h th b tal loc ty f th pl t abo t th S The th t n es ry d pe d pon th t m g f th m

The last prop l on equirement i s milar to the fi t but applied in re e se The ehicle i de el r ated fr m its olar tra sfer o bit to a satellite orbit about the ta g t planet Th maneu er requ res rel ati ely high a elerat n to o ercom a high gravi t t onal field although n t o h gh as i requ red for a land n m neu er b ca se the eh cle may make a p ral appr a h F r e gines of h gh thru t weigl t r tio (l rg r than 0 5) the appr ach p th to the ta g t pl n t is en itive t the t mi g f the thru t appl cat o It w ll may b that the in tial capture o b t qui e rre t on Th pe d with which the man ver is to b car ied out determines to some e tent the r qu red thru t

Mi s o n ds Interplan t ry mi sion e n be gr ped in th ee teg ries each equir ng a d f f nt m nt f nergy for interplanetary tran fe o b ts (1) mi n the immed ate i inity of E th d Moo (2) mi i n with n the nner o- l r sy tems out to th b t of Ma s and (3) mis-s o t th uter l r s tem bey nd Ma s

F r the fi t cate ry of mi on hemic l sys-tem e adeq te but a c lerati ns bel w 0 01 g r too m ll to be useful Po s bly uclear or i ome lim ted ca es olar h at ng eng es ould als be u d f r m f the t an f r m ne er

Fo m o s w th the i ner lar y t m ac el rat o s of 0 0001 g a e at sfact ry f r the d s t n es a d fl ht time n l ed The s m p op l n sy t m m ti d ab e a al o suitable for the e fl ght except that ery effic nt electrical g ne m y b added

F r mi n t the o ter lar sy tem a cel ra t s gr ate th n 0 00001 g w ld p od ce at s f t j t j to e wh ppl ed n the peri ds of sever l m ths r year n c sar f r uch flight B c u of th r h gh p cifi impul e the elect i al p op l n systems a e uniquely qu l fied f th e mis n

In e l it e n b a d th t i t plan tary h l s w ll e t f e l sta es or st ps d that e h tag w ll hav its own p opuls n sy tem D pe d ng up n th ex t m eu th g nes in th r us t ges w ll be d ffe nt a d it i f a ibl t e th m type of tag f m than ne n t rpl n t ry ma e

Be au f the eed f both h h a d l w thr t d i g a terpl n tary flight a p pul n ystem th t c uld be th ttled w ld be u ful in me e p id d th ch g n th st we e n t a c mp ed by s r o l s in pe f rmance The t p decay r ck t n l a ock t and electric l dev n be th ttled If pecifi impul does n t cha u fa bly th ottl g e n a v h le e ght nd z

Pre nt-d y p wer suppl w th p c fi w ght f 20-30 lb/hp ng pr p lla t that d l v r spe cifi imp l es f 300-400 ll w m der tely fa t o d t ipt Mar II ocket eng o ld be t ted t w ld p de the thru t f ever l of th lem t rv ma Th pr p llant n t pended n e l r ma r wo ld be a ailabl

1000–2000 F (*see* SOLAR ENGINE) At the Earth s distance from the Sun a reflector area of 8 ft /kw is needed if 100% of the captured radiation is con verted to power (*see* SOLAR CONSTANT) Consider ing all the losses probable in such a heater from accuracy with which the reflector is pointed at the Sun to efficiency of a solar boiler the reflector area may need to be 80 ft^2/kw At Mars distance from the Sun the reflector would need to be 200 ft /kw Just how such a reflector for a high power system would be transported into space remains to be de termined

Photon propulsion The radiation pressure of the photons from the Sun is about 10^{-7} lb/ft at the Earth s distance The total pressure due to action and reaction on a perfectly reflecting surface would be twice this value Although force is limited by being directed only away from the Sun solar sail ing can provide low thrusts and attitude con trol turning a spaceship completely ar und in a few hours Because no working fluid is carried in the vehicle this type of propulsion is economical in weight

For the vehicle to carry its own light ource a photon rocket of adequate thrust would necessitate energies far beyond present capabilities Because the photon velocity is the speed of light relativi tic effects must be considered Also the need for cool ing of mirrors precludes a practical device using pre ent technology

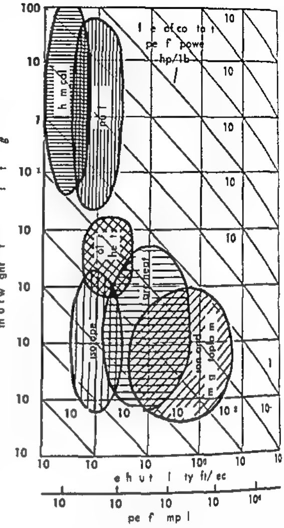
Performance evaluation Each space flight re quires particular en ine performance Thus there is no best engine but there are engine better suited for some missions than for others The table presents data for the principal types of en gine Figure 2 shows the relation of acceleration (which i also the thrust weight ratio of the ve hicle) to specific impulse (or exhaust velocity) and to specific power (which is here the ratio of kinetic energy in the jet per unit time to the over all weight of the vehicle including its ource of energy)

Chem cal and nuclear rockets provide high thrust for short durations The other engines operate for long durations at low thrust For h rt trip rapid acceleration is desirable for long trips slow ac

Ra ge of sp cif c imp lse thrust weight ratio and durat o

Sy t m	Sp c f c m p l	Tl t t w gl t t	Typ l l t n
Cl m l	00–4 0	10^{-2}–10	M t (l gh th t) H (l w th t)
F s	500–1 100	10^{-2}–10	S m l m l y t m
I t p lec y	400–700	10 10	D y
A h t g	400– 000	10^{-4}–10	D y
M g to- pl m	5 000– 000	10 10	W k
I n	5 000–60 000	10 10	M th
Sol h t g	400–700	10^{-2}–10	D y

\ p



F g 2 Regions of accele ations and spec fc po n for various rockets (J ur al f the Ae o/Space S e ces)

celeration may produce usable over all flight time For such service as interplanetary freight the high specific impulse of the electrical units would al w a vehicle so powered to carry a heavier payload than if driven by a chemical rocket

Trajectory requirements The seven ba ic inter planetary maneuvers are presented in Fig 3 to gether with the engines suitable for each The inter planetary flight really starts from a atellite orbit beyond the greater part of the Earth s atmo phe It is assumed that the energy neces ary to lift a vehicle off the ground and to put it into a atellite orl it is provided by separated rocket boo ter e hicle To minimize the energy nece sary to o er come the relatively strong gravitational field the thru t should be applied during a brief period Chemical and nuclear rockets are therefore the only suitable engines for this maneu er *Inter planetary propulsion* need supply only the energy to accelerate from orl ital velocity and for the otl er interplanetary maneuvers

Interplanetary orl it transfer is the next maneu ver Ba ically it is tl e o ercoming of the gra ita tional field of the Sun and the correcting for dif ferences in tangential velocities of the launching

m	h mi	r	lo a p y	h ll a	m a t pl m		sol h r a	sol r
escape from orbit	○	○	○	○	○	○	○	○
inte pl ne ry tr f		○	○	○	○	○	○	○
ch ng f pl ne	○	○	○	○	○	○	○	○
one ta o	○	○	○	○	○	○	○	○
trajectory correctio	○	○	○	○	○	○	○	●
targ t pproach	○	○	○	○	○	○	○	●
cap re	○	○	○	○	○	○	○	●

○ tabl ○ acc p bl ● nd robl

force g neral d rection f rad tio

Fig 3 S t b l ty f o p p l o ystem to d'ff re t t pl t ry m vers. U t f the A /Sp S e)

a d the t rg t pla et Th de l ed m m m n e g attai ed when fiv g th a apres y f so lled H hm n ell p e t t g t at it phe l t th b t f th o te pl net nd at it pe h l n t th bit f the n pl n t and h th Sun at it p um focu A sep r te ppl t n f thru t m y be n ecessary f th man u er n f fa te tr f but equ r g g t r f ll wed beca the gy m y be ap pl ed e th me t m th e p ma S Ericson.

Th b t f e h pla t t lied t a d ff re t but m ll a gle t the pl n of th ecl ptic De pe ding upon th po t of l un h ng and the t g t pla t and pon th regi n f th flight t ject ry whi h th le ha ges fr m th pl n of th b t f n t la et t the pla e f th b t f th th ergy r pp ec ble rgy m y b q ed

h l t t m y need t l f u h pe t n at al b mat rad m m n tt n r f ec g l r e gy On wa t a h ev thi co t ol t l w thr t p o pul t m c u f b t l r f gr at mport A mult ple n zl m n p p ll t e tem n tr f sol d an n p es u e r fl tors appe rs t be d all ted f th m n u

T ject ry co rect n be mad l wly The rgy req d f h rre t d pe d up n ther h e l r d fa t pe all th tro n g t devi e d n d t ol a d p n th pl t a d th u y f the map f th l syst m

th h l pp hes th ta get pl n t a h g in loc ty may be need d t m t h th b tal locity f th pl nt ab ut th Su The thru t r d pe d t tum n f th m n r

Th la t prop l n requ r m nt m l r t the fi t but appl ed in rev r e The vel le l dec l r ated fr m t solar tr n fer l t t a t ll t l t about the t rg t plan t Th m e r r t r r l att els h gh a c lerati n t mes ome a l gh g avi tat n l field alth ugh n t so high a t re red f r a landing ma e er becau the h cl may mak a p r l app ach f r ngin of high thr t weight rat (larg r than 0.5) the appr a h pat l t tl targ t pl n t t t tl t ming f tl t t t p pl catio n It w ll may be tl at th m t l e pture rl t requires correct Tl pee l wit wl h th man u e r t be carr ed t d t rmin t m e tent th req ed thr t.

M n ds Interplan t r m a be grouped n th ee c teg s, each req i ing a d f ferent am t f ene gy f r int plan tary tran fer b t (1) mi m th immediat anit f E th d M ( ) mi w thin th inn r o lar tem ut t th rb t f Mar and (3) m to th o t r ol r y tem be nd Mar

F the fir t cat g ry f m n l mi l y tem ar a f q te h t a el rat fel w 0.01 g ar too mall t be u ef l F lly ucl ar or in som l mited a es lar l at g engines could al be sed f f th t n f man r

F r mi with n th r sola t m e l rat f 0.0001 g a at f t ry f th d ta es nd fl ght t m t l ed Th m pr pul n y tem m t ed also ar also t l l f r these fl ght g pt th t e y eff i nt electri l ng nes may be added

F mi n t the ter solar sy t m a l ra ti n gre t e th n 0.00001 g w uld p od sat fa t y tr j t r es wh n ppl ed the p ul f ev ral m th r y t neces ary f r uch flight Because of th ir h gh pecifi impul the electri al pr pul y tem a uniq ly q al fied f th e mi

In ge e l t can be said that interplan t r es hi l w ll n t of al t ges tep and that h t g w ll ha e tt wn p l y t m D p d ng upon th t man u er th ng es in th tage will d ff nt d t f a tle t n th ame type f t g f r mor than on in terpl net y ma u e

B au e f th eed f r both h gh a d l w th u t d g a nte plan t ry flight a pr p l i n y t m th t uld be th tt l d w uld t u eful in some es p o ded th h ng n thru t we e t mp n d b u l p f rman The t pe dec y rock t nuclea rock t and lect cal d e n be th ttled If pecific impul does t ha g u f rably thr ttl ng c n a v ehicl weight a d

P e nt day p w uppl with cifi weight f 20–30 lb/hp u n p op lla ts th t del r pe fi mp l e f 300–400 ec all w a m derately f st und t p to M s If o k t e g e uld be r tarted it w uld pr v d the th st fo se eral f th s te el m t ry m neu r The p pell nt not xp ded n a l e man u r ould be a il ble

for later portions of the trip Even so having at least two stages—one for high and one for low thrust—seems favorable for interplanetary and or bit transfer maneuvers

Environment During any of these missions the engine with the vehicle is exposed to unusual en vironmental conditions Prolonged exposure to high vacuum precludes use of materials that evap orate For example some soldered joints contain materials that will slowly evaporate in space

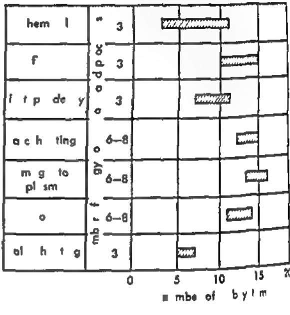
Over most of the interplanetary trajectory gravi tational acceleration will be very small Po itive acting switches and other components are the necessary gravity cannot provide a return force Similarly a liquid and its vapor will be difficult to separate In space electromagnetic radiati n and corpuscular impacts may alter the properties of the materials used in the engine and in the vehicle

The over all vehicle should maintain thermal equilibrium Ambient temperature can be con

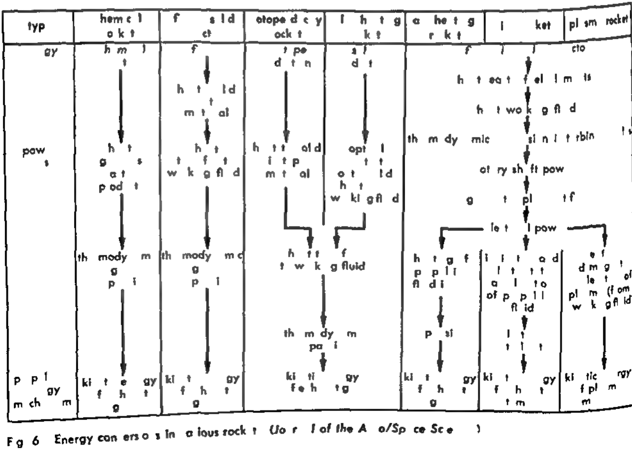
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
lq d p pella t h m l	○	○	○	○	○	○	○	○	○
ol d p p ll t h m l	○	●	○	○	○	○	●	○	○
f s	○	○	●	○	○	●	●	○	●
t p	●	○	○	○	○	○	○	○	○
c h t	●	○	○	○	○	●	○	○	●
m g topl ma	●	●	○	○	○	●	○	○	●
	●	●	○	○	○	●	○	○	●
s l he t	○	○	○	○	○	○	○	●	○
l l	●	○	○	●	○	○	○	○	○

○ w ll k ow f bl ○ t o l m ted
● l g ly pl d d ff lt

Fg 4 Compa on of technical featu es of propul on syst ms (Jo rnal of th Ae o/Spa e Sc e ces)



Fg 5 Relat e comple ity of va o s prop lso syt tems (J rnal of th Aero/Sp c Sc e ces)



Fg 6 Energy con ers o s in a ious rock t (Jo r l of the A o/Sp ce Sc e)

e lled by rfa e mater al that re e e rad at on rom th Su nd ad te energy int pac Energy rom nten ely hot port ons of the ngi e requ re ffecti e d tr l t n A large th rmody am c l eat k (ad ator) nec ary f r me eng nes n es the h a d fr m mete te impact

Sm ll f st m v ng part cles ar a hazard to all pa e h cle Pen trat on by a part le m y e lo s ol g s pr pr pell nt or coolant or m v a t e s e nce trati ns eriou f r such highly l aded k n Solid pr pellants may l e p e m tu ely gnited m ch ry may be e dered i perat e Pr t ct e me u e a h de dupl cat ng sy tem m im zing th ize f eh cle a d the ex t sed urf ce and pr d ng hea y wall The hea y wall may al b eeded fo struct r l stre gth as in li m cal r ket n for ad t on p tection a nuclea o k t

Until a f w i t rplan t ry p obe return w th d ta the exact nvi onme t of pac rema ns the bje t of onjecture

Engine development Eng des gn and oper t nal requ ements ry fr m m s n t m s n M y mi r q e th appl at on of thru t at d ff e t t m s ally by taging or occa ionally by e t rtabl nes Ign t n n a v c um and e p l f l quids f m t nk at ro g ty a e d ffi lt Th e a d the g n devel pm ntal f at es re umm rized in F g 4

F n g ti n l b erv t ns a d f r ma ce er ing the p p l n y tem may be eq i ed to p o d c tely ntr ll ble t rque a d l w thr t n d et th r than th ginal fl ght d r t n These d th r ope at o l equ r m nt w ll n fi n e the lect of the e gi f pe fic m

F mpari n i ba p p l on y tem latu el abil ty an be defined b ed on th n mbe f m jo ub y tem nd f the mple ity f gy O th b i tl el t cal yst ma t d to be th lea t r l able t sh wn Fig 5 Th m wh t rbitrary energy on o s d d f tl ev l at a h wn n Fig 6 The l qu d m n pr pella t s t m appears to be p rt larly tt t not only f it sim pl t b t l f its ab l ty t top and re t rt a d f r t d g fl bil t O the l a of the e ject ed mt so th hem al r k t ca be pected to b th m t rel bl e gi e f a l ng t m t m

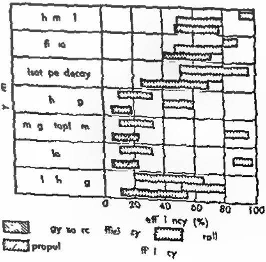
Lo g d mpli ted p fl ghts w ll q e l b l t th t x eed th e f much qu pm t w sed Ea th T a ason ble n s e t l fl ght m y nec t t uch xte gr u d t ti g nde m lated d t n t m k es l fl ght te t g m d r ble d h ap D pl t (r d d t) y t m w ll b u ed f l l l t Al er l l bl eng es th p es w ll b l t r d Th f h g ne h el b l t f 0 99 (1 f l 100 t) l t r 1 7 e g 5 f a d a p w ll f l nly o 9930 ope at o Only tl ch m cal rocket has been dev l ped s ifficie tly so that the r l bil ty is high eno gh f r u h clu ters g t b eff ti For the next few ye r it will b tl e nly a ilable e g ne fo int rpl netary flight Work other gi e type h s been i iti ted (*Fig 7*)

Th e gines th t d rve th gre test eff rt are th l wing the great t pr m se both in ffei nt *of the r e ergy so ce and in effici t e n r*

l q d propell t	O	O	O	O	O	O
sol d p pell t	O	O	O	O	O	O
monopr pella t	O	O	O	O	●	●
f ion	O	◐	◐	◐	●	●
f io	◐	◐	●	●	●	●
radioo t isotope dec y	◐	◐	◐	●	●	●
hea g	◐	◐	◐	●	●	●
mag pla ma	O	◐	●	●	●	●
ion	O	◐	◐	●	●	●
sol h t g	O	◐	◐	◐	●	●
sol l	◐	●	●	●	●	●

O ompl d l bl
d w y
● accompl hed or l bl

Fig 7 De elopm t t t of va io ock t gi s. (U f f th A /Spa Scie)



Fg 8 R l t ff c f p w lo diffe t p p l y t m U l f the Ae / Sp S)

sion of energy to high thrust as summarized in Fig 8 The chemical and nuclear engines are the only ones with a high acceleration capability If an efficient lightweight electric generator could be found the electric systems with their versatility would be highly attractive and accelerations higher than 0 00001 *g* could be attained *See* SATELLITE ARTIFICIAL SPACE STATION SPACE TECHNOLOGY *see also* SPACE FLIGHT SPACE VEHICLE SPACE CRAFT STRUCTURE [G P S]

Bibliography M Alperin and H F Gregory (eds) *Vistas in Astronautics* vol 2 1959 M Alperin and G P Sutton (eds) *Advanced Propulsion Systems* 1959 *Astronautics* vol 4 no 10 1959 *J Q Brantley Jr and D R Rhodes (eds) IRE Trans* MIL 3 1959 G P Sutton Rocket propulsion systems for interplanetary flight *J Aero/Space Sci* 26(10) 609–625 1959

Interpolation

A process in mathematics used to estimate an intermediate value of one (dependent) variable which is a function of a second (independent) variable when values of the dependent variable corresponding to several discrete values of the independent variable are known An example may illustrate the proce s

Suppose as is often the case that it is desired to describe graphically the results of an experiment in which some quantity Q is measured for example the electrical resistance of a wire for each of a set of N values of a second variable v representing perhaps the temperature of the wire Let the numbers Q $i = 1$ 2 N be the measurements made of Q and the numbers i be those of the variable i These numbers representing the raw data from the experiment are usually given in the form of a table with each Q listed opposite the corresponding i The problem of interpolation is to use the above discrete data to predict the alue of Q corresponding to any value of v lying between the above If the value of v is permitted to lie outside these i the somewhat more risky process of extrapolation is used *See* EXTRAPOLATION

Graphical interpolation The above experimental data may be expressed in graphical forms by plotting a point on a sheet of paper for each pair of values $(t_i Q_i)$ of the variables One establishes suitable scales by letting one inch represent a en number of units of v and of Q If v is considered to be the independent varial le one usually lets the horizontal displacement of the ith point repre ent t and its vertical displacement represent Q

If for simplicity it is assumed that the experimental errors in the data can be neglected then the problem of interpolation becomes that of drawing a curve through the N data points P_i having coordinates $(x_i y_i)$ that are prop rtional to the numbers t_i and Q_i re pectively so as to gi e an accurate prediction of the value Q for all intermediate alues of t Since it is at once clear that tl e N mea urements made would be consistent with any curve passing through the point ome a tional a sumptions are necessary in order to j tify drawing any particular curve through the points Usually one assumes that the t are close enough together that a smooth curve with a ple a variation as possible should be drawn through the points

In practice the numbers t and Q will contain some experimental error and therefore one should not require that the curve pa s exactl through the points The greater the experimental uncertainty the farther one can expect the true curve to deviate from the individual points In some cases one uses the points only to ugge t the type of simple curve to be drawn and then adju ts this type of curve to pass as near the indi idual points as possible This may be done by choo ing a function that contains a few arbitrary parameter that may be so adjusted as to make the plot of the function miss the points as little as po sible For a more complete discussion of this topic *see* CURVE FITTING For many purposes however one u es a French curve and orients it so that one of its edges passes very near a group of the point Having drawn in this portion of the curve the edge of the French curve is moved so as to approximate the next group of points An attempt is made to join up these portions of the curve in such a way that there is no discontinuity of slope or curvature at any point

Tabular interpolation This includes methods for finding from a table the values of the dependent variable for intermediate values of the independent variable Its purpose is the same as graphical interpolation but one seeks a formula for calculating the value of the dependent variable rather than relying on a measurement of the ordinate of a curve

For the purposes of this discu sion it will be assumed that x_i and $y_i (i = 1\ 2$ $N)$ representing tabulated values of the independent and dependent variables respectively are accurate to the full number of figures given Interpolation then involves finding an interpolating function $P(x)$ satifying the requirement that to the number of figures given the plot of Eq (1) pass through a se

$$y = P(x) \tag{1}$$

lected number of points of the set having coordinates $(x\ y)$ The interpolating function $P(x)$ should be of such a f rm that it is made to pa s readily thr ugh the selected point and is ea ily calculated for any intermediate value of x Since many chemes are known f determining quickly tl e unique th degree polyn mial that sati fies Eq (1) at any $n + 1$ of the tal ulated alue and since the alue of such a p lyn mial may l e c mputed u ing only n multiplications and n addition p lynomial are the mo t c mm n f rm of interpolating functi n

If the sul ript on x and y are rea igned so tl at the po nt through which Eq (1) pa are n w $(x\ y)$ $(x_1 y)$ $x_n)$ tl e polyno-

In ded i Eq (1) may be wr tten down by in
:t and o e has

$$y = \sum_{k=} \frac{L_k(x)}{L(x)} y_k \qquad (2)$$

re

$$L_k( ) = \frac{(x-x)(x-x_1) \qquad (-x)}{(x-x_k)} \qquad (3)$$

i i Lagrange s nterpolati n f rmul f r u ally pa ed rd nat s S nc $L(x)$ van hes for x in the t x x x except x sub t ing $x = x$ n the ight hand ide of Eq (1) gi es e t ly o e o e o t rm Th term h s the lu y sr q i ed

F r $n = 1$ Eqs ( ) nd (3) g e i e t th u ti n

$$y = \frac{x-x}{x-x_1} y + \frac{x-x}{x-x_1} y_1 \qquad (4)$$

iose pl t a tra ght l e on ecting th po nt ωy) nd (x y) Su h n inte pol t n i re rred t l n ar nt rpol ti and ed in all me t ry d c on of int pol i n h wever other q i l nt form of thi eq at on g en be w Eq (12) is m re fr n u ed in these a es S ppo e th t bl w obta ned f m th eq n $y = f(x)$ n wh h $f(x)$ i some math mat c l i h i g cont nu s d ti es of all rder p t and n lu l ng th (+ 1)th It i then po t l t bt n an n rat exp es i f r mi rmed te lu f $f(x)$ by addi g t the r ght h d side f Eq (2) so- all d m i d i rm

$$\frac{(-x)(-x) \qquad (x- \ )}{(+1)!} f^{( )}(\xi) \qquad (5)$$

h e f^{n} (ξ) th (+ 1)th d ri ti e f $f(x)$ at m p t $= \xi$ ly g b tw n the mall e t a d l gest l th l es x_0, x x_n S th al n f ξ i n t known the remai d r term u d m r ly t set an uppe l m t on th tru c t on o t od ed by i g Lag g a t te pol tion form)

If th d te a eq lly p ced th t s = + h wh r h i the nterv l of t bul t n Lagr ge s nterp lat n f rmul mpl fies d ably and may b wr tt

$$y = \sum_{k=-p} A( )y = A( )y \ + $$

$$+ A( )y + \qquad + A( )y \qquad (6)$$

wh th degr f nt polati g p lyn m al th t w l th gh th +1 p nt (x_{-p},y) (x_{n-p},y) H p s th l rgest nteg r l s th n or q al t /2 d the A ( ) A ( ) e polynom l th ar bl

$$= \frac{x - \quad}{h} \qquad (7)$$

The latte p lyn m als h ve b en t b l ted a fu t f u

Inverse interpolation If the valu f y i known and the alue of the correspon ling independ nt variable x i de red ne ha th pr l l m of in er e interpolati n S nce the polyn mial A (u) in Eq (6) are kn wn fu cti n f u and th alues of y and y_k are also known th nly nkn wn in thi equati n i u Thu the pr l lem redu es t that of find ng a re l root u f an nth-degree polyn mial n the ra ge $0 < u < 1$ (F d sc i n f nu meri al methods f r sol ing f r su h a root and f r m re inform ti n on i terpol ti n s NUMER ICAL ANALY IS) Ha ng f u d u n may f nd x f m Fq (7)

One may also perf rm an inv rse int rpolati n by tre t ng x as a f ti n f y S n e howev r the interval between th y are n t eq al it i nee es ary t empl y the g neral interpolati n f r mula of Fq ( ) with the x and y int rchanged

Round-off errors In th tal ulated values, ro and off errors i res lting fr m th nee l to xp es the entr es y of th tabl a fin t decimal w ll cause an additi nal rr r in the int rpolated val e of y that mu t be added t th trunc ti n err r dis cu ed before The effect f these rr r on th appl ati f Lagrang i t rpolati n f rm il i seen by Eq (6) t be a total er y in y n l y

$$\epsilon_y = \sum A_k(u)\epsilon_k \qquad (8)$$

Letti g be malle t po ti e n mber ti lying the co d ti e > | ϵ_k| f r all k ne has fr m Eq (8) that

$$|\epsilon_y| \le \sum |A( )||\epsilon_k| \le \sum_k |A_k( )| \qquad (9)$$

S ce the s m of the A_k( ) i eq l t l the f t r

$$\sum_k |A_k( )|$$

n Eq (9) s u ually n t much l g r th n 2 o 3 a d th s th i t rpol ted alue f y has abo it the am round off err a the i di dual entries

Use of finite differences F some purposes it i mo e c nv ent to u e an interpolat g f rmula based n t mu h n the ent es y of a ent al d ffe enc tabl as pon their diff rences

$$\begin{array}{c|cccccc}
x_{-1} & y_{-1} & & & & & \\
 & & \delta y \quad 2 & & & & \\
x \ 1 & y & & \delta^2 y \ 1 & & & \\
 & & \delta y_{-1} & & \delta \ y_{-1/2} & & \\
x & y & & \delta^2 y_0 & & \delta^4 y & \\
 & & \delta y_{1/2} & & \delta^3 y \ / & & \\
x & y_1 & & \delta^2 y_1 & & \delta^4 y_1 & \\
 & & \delta y \ /2 & & \delta^3 y & & \\
x_2 & y & & \delta^2 y & & & \\
 & & \delta y_{5/2} & & & & \\
x_3 & y_3 & & & & &
\end{array}$$

E ch d ff e δ y is obtained by subt acti g th q antity immedi t ly bo e and to the left of

sion of energy to high thrust as summarized in Fig 8 The chemical and nuclear engines are the only ones with a high acceleration capability If an efficient lightweight electric generator could be found the electric systems with their versatility would be highly attractive and accelerations higher than 0 00001 g could be attained *See* SATELLITE ARTIFICIAL SPACE STATION SPACE TECHNOLOGY *see also* SPACE FLIGHT SPACE VEHICLE SPACECRAFT STRUCTURE [C P S]

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In practice the numbers t_i and Q_i will contain some experimental error and therefore one should not require that the curve pass exactly through the points The greater the experimental uncertainty the farther one can expect the true curve to deviate from the individual points In some cases one uses the points only to suggest the type of simple curve to be drawn and then adjusts this type of curve to pass as near the individual points as possible This may be done by choosing a function that contains a few arbitrary parameters that may be so adjusted as to make the plot of the function miss the points as little as possible For a more complete discussion of this topic *see* CURVE FITTING For many purposes however one uses a French curve and orients it so that one of its edges passes very near a group of the points Having drawn in this portion of the curve the edge of the French curve is moved so as to approximate the next group of points An attempt is made to join up these portions of the curve in such a way that there is no discontinuity of slope or curvature at any point

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$$y = P(x) \tag{1}$$

should be of such a form that it is made to pass readily through the selected points and is easily calculated for any intermediate value of x Since many schemes are known for determining quickly the unique nth degree polynomial that satisfies Eq (1) at any $n + 1$ of the tabulated values and since the value of such a polynomial may be computed using only n multiplications and n additions polynomials are the most common form of interpolating function

If the subscripts on x and y are reassigned so that the points through which Eq (1) passes are now $(x_0 y_0)$ $(x_1 y_1)$ $(x_n y_n)$ the polyno-

i e l es of $f(\ )$ tabulated at some interval $x = h$ they are admi ably d pted t numerical omputat ons F thi r a on m t numerical o- ution of d ffe ntial equat n m ol e approx iating the equ tion by a u table d fference equa on

For ord nary diffe ential eq at on the transfor iation to a d ff rence quation can be made by re- l c ng h deri ati e in the equati by the ap- opr ate diffe ence expre on rd ng to the ormul

$$f^{(2k)}(\ ) \rightarrow \frac{1}{h^{2k}} \delta^{2k} f(\ )$$

$$^{2k+}(x) \rightarrow \frac{1}{2h^{2k+1}}\left[\delta^{2k+1}f\left(x+\frac{h}{2}\right)+\delta^{2k+1}f\left(x-\frac{h}{2}\right)\right] \qquad (15)$$

here $f\ \ (x)$ de ignat the th deri ati e f (x) The d ff r ce equation resulting can then me ti ned befo be u ed to expre s the r la o h p betw en the lues of $f(x)$ at th discrete nts $x = x + sh$ $s = 0\ 1\ 2$, n

Partial difference equations Suppo e one hoo to pe ify a funct on of tw ariables (xy) by giving lue t om reg l r array f oints in the y plane ha ng coordinat s $(x_m\ y\ )$ h n, n pl f l n ar p rtial d fferent al equa fo $f(xy)$ e ha l n ar partial d ffer n qu t n

$$\sum A\ f(\ _{i+}y_{j+}) = g(\ \ y) \qquad (16)$$

h e $g(xy)$ a kn wn fu ti a d i nd j ny f th t f inte f wh h the d ffer nc qu ha gn fi an e A diff re ce equation n h ch s me of the $f(\ \ y_j\ )$ cu to a power the th n the F t s t rmed n l n r d ff rence q ti

If empl ys qua e latt e make-up of the oints

$$x_m = \ \ o + mh$$
$$y\ = y_0 + nh \qquad (17)$$

i n Lapl d ff nti l quatio s app ox i ted by th d ffe n q t on

$$f_{+\ i} + f\ \ \ i + f\ \ i + f\ \ \ - 4f\ = 0 \qquad (18)$$

h r f r ampl ty lets

$$f\ \ = f(x_m\ y\ ) \qquad (19)$$

e Graphic t t iods Lattice (mathe iatics)

[K.S.K.]

B bl g phy K. S K nz, *N m ri al Ana y is* 9 7 *T bl f Log a gua l t p lat n C effi nt* 1944

Interstellar matter

h mate i l betw e th ta s Int t lla matt k t p e n known in many way N ly ny l xp s ph tograph f a a n the l lky Way t ke w th a fa t t l pe w ll how bright pat hes of nebul u material The ligl t fr m the patches xhibit emi ion l ne spectra charac teri tic of a gas at l w den ity Other cl uds are bright becau e they reflect the l ght of a n arl y star or sta s and hence mu t be made f mall s l d parti les. The e cl ud and the illuminating star have s milar pectra Frequently stars h e a redder color than i predicted by their pectral characteri tics the result of int rvening material not unlike mall dust particles which reddens any light pa ing thr ugh. Di tant stars often exhibit absorption l nes in their spectra which are produced by interstellar gas Fin lly the light of many stars is polarized a d the correlation between the d gree of polarization and the d tance of the star suggests that a material of crystalline form exi t in interstellar space

Nearly all interstellar material in our galaxy is located in the spiral arms Rad o ob rvati ns have detected hydrogen ga in the nucl us of the galaxy but no obscuring matter has been ob erved In other galaxies the ch racteri tic emissi n spectrum f interst llar gas is frequently seen particularly in the spiral galaxies Spiral galaxi s seen edge-on always show a c nspicuous band of absorbi g material silhouetted again t the bright nucleu and spiral arms *S e* Galaxy external Galaxy the.

Bright gaseous nebulae Only in the neighbor hood of a tar hot enough and bright en ugh t e cite the gas to luminescence can ther be a bright g eou nebula (s Nebula gaseous) The tar t elf may be the ource f the ga s i the ca in pla et ry nebul a d the shell around e vae a d p rno ae (s Crab nebula) Th Ori n nebul i the best kn wn d ff ga eou nel ul (s O ion nebula) The electr n den ities det r m ned for g eous neb l e ar l th order of 10 10^4 lectr n /cm and the k n tic temp ratu es are a und 10 000 K. Th r compo iti n a e s m lar t tellar atm phere e n t ng of abo t 90% hydr gen atoms and 9% h l um t m l y number of t m

Alth ugh o d ary ga eo s neb lae requ e th p ese e of a defin te cl ud of inter t llar ga oc ur n mo t part of r gal xy with a h gh gh d ns ty t be detect ble by spect l em e a t th ic n t of y hot bright tar Beca the ga is l g ly at m *hyd* en and m tly i zed uch f i t object a called H II regi ns H re the d nsity may be s l w a l atom/cm and the r d u of the reg o of ion zed hydr g n m y exte d t te 10 parsecs (326 light years) H I (ne t l hydrogen) regio s ha e been d te ted by bs rv ng th hyd og n em s on line of 21-cm wa el gth with rad o tele pes Here aga n the d n ty is about 1 atom/cm a de ty wh ch se ms t be typ c l f th pace in th r g o of o r gal axy occup ed b the Sun

Reflection nebulae Frequentl b ight d ffu nebul e ar ob rv d p e ing dark l p c tra. Su h nebulae *contain* mall sol d part cle or g a n wh ch reflect the l ght f ne rby star o

it from the quantity immediately below and to the left thus

$$\delta^k y_s = \delta^{k-1} y_{s+1/2} - \delta^{k-1} y_{s-1/2} \qquad (10)$$

where k and $2s$ are required to be integers For example

$$\delta y_{1/2} = y_1 - y_0 \quad \text{and} \quad \delta^2 y_0 = \delta y_{1/2} - \delta y_{-1/2}$$

An interesting property of a difference table is that if y the dependent variable tabulated is a polynomial of the nth degree in x its kth difference column will represent a polynomial of degree $n - k$ In particular its nth differences will all be equal and all higher differences will be zero For example consider a table of cubes and the difference table formed from it by the rule given above

x	$y = x^3$			
0	0			
		1		
1	1		6	
		7		6
2	8		12		0
		19		6
3	27		18		0
		37		6
4	64		24		0
		61		6
5	125		30	
		91		
6	216			

Most functions $f(x)$ when tabulated at a small enough interval $\Delta x = h$ behave approximately as polynomials and therefore give rise to a difference table in which some order of difference is nearly constant Consider for example the difference table of log x in which the third differences fluctuate between 7 and 9 times 10

x	$y = \log_{10} x$	δy	$\delta^2 y$	$\delta^3 y$
1 00	0 0000 000			
		43 214		
1 01	0 0043 214		−426	
		42 788		[illegible]
1 02	0 0086 002		−418	
		42 3[illegible]0		9
1 03	0 0128 372		−409	
		41 961		[illegible]
1 04	0 0170 333		−401	
		41 560		7
1 05	0 0211 893		−394	
		41 166		
1 06	0 0253 059			

Experimental data if taken at small enough interval of the independent variable would be expected to exhibit much the same behavior as a mathematical function except for the presence of experimental error The presence of the latter will cause the differences to have a more or less random fluctuation The size of the fluctuation may in fact be used to indicate the number of significant figures in the data

The constancy of the third differences for log x indicates that for the accuracy and the interval used a third degree polynomial may be employed as an interpolating function Since such a polynomial is determined by the choice of four coefficients one would expect the interpolation formula to involve four numbers derivable from the difference table Thus the forward interpolation formula of Gauss

$$y = y_0 + u\,\delta y_{1/2} + \frac{1}{2}u(u-1)\,\delta^2 y_0$$
$$+ \frac{1}{3!}u(u^2-1)\,\delta^3 y_{1/2} + \frac{1}{4!}u(u^2-1)(u-2)\,\delta^4 y_0$$
$$+ \frac{1}{5!}u(u^2-1)(u^2-4)\,\delta^5 y_{1/2} + \qquad (11$$

If terminated after the fourth term it represe a third degree polynomial in $u = (x - x_0)/h$ an hence in x It involves the four constants y_0, δy_1 $\delta^2 y_0$ and $\delta^3 y_{1/2}$ Since any one of the entries the y column may be chosen as y_0 the difference required are picked from a central difference ta ble for example in relationship to this entry Th interpolating polynomial obtained passes throu the four points $(x_{-1}\,y_{-1})$ $(x_0\,y_0)$ $(x_1\,y_1)$ a $(x_2\,y_2)$ In general the interpolating polynom will pass through only those points whose y ordinate is needed to form the differences used the formula

If one terminates the series in Eq (11) aft the second term one obtains the formula

$$y = y_0 + u\delta y_{1/2} = y_0 + u(y_1 - y_0) \qquad (1$$

This is the linear interpolation formula most oft used when making a simple interpolation in a ble

There are a great variety of interpolation f mulas Gregory Newton s Stirling s and Be that differ mainly in the choice of differences u to specify the interpolating polynomial

Difference equations Repeated application Eq (10) may be used to express any difference terms of the tabulated values thus for exam

$$\delta y_{1/2} = y_1 - y_0 \qquad ($$
$$\delta^2 y_0 = y_1 - 2y_0 + y_{-1}$$

Expressed in a more general form these become

$$\delta f(x) = f\left(x + \frac{h}{2}\right) - f\left(x - \frac{h}{2}\right) \qquad ($$
$$\delta^2 f(x) = f(x+h) - 2f(x) + f(x-h)$$

If one sets the second difference equal to zero obtains a so called difference equation for $f($ In general a difference equation is any equat relating the values of $f(x)$ at discrete values o

Difference equations play much the same in analytical work as differential equations cause they may be interpreted in terms of

group of stars Studies of these particles in reflection nebulae suggest that they have high reflectivities and are nonmetallic Probably they are ice crystals or compounds made up of the lighter elements The nebulae always appear slightly bluer in color than the illuminating stars indicating that the particle diameters are in the vicinity of 10 cm

Light scattered by small particles is usually polarized and photographs of reflection nebulae taken through polarizing materials show that the polarization can be as high as 35% Also the effects of radiation pressure can frequently be seen particularly when there are highly luminous stars in the vicinity of the nebula (Fig 1)

Frequently bright diffuse nebulae such as the Orion nebula are composed of both gas and particles as is evidenced by their spectra which contain both emission and absorption features

Dark nebulae When silhouetted against a rich star field or a bright nebula a cloud of solid particles becomes apparent by absorbing or scattering away radiation directed towards the observer Many dark nebulae are to be seen in the Milky Way regions of the sky where the light from distant stars is dimmed reddened and often polarized The distance to a dark nebula can be found approximately by determining the distance to the most distant unreddened (or unpolarized) tars, which must of course lie between the Earth and the nebula Also if it is assumed that statistically all tars are of the same intrinsic brightness a di tance can be estimated Here counts of stars per unit of angular area in the sky within a small range of apparent magnitude or brightness are made and compared with neighboring areas of the ky The dimming effect of the nebula will cau e a sudden decrease in the density of stars fainter than a critical apparent brightness which correspond statistically to a certain distance

One of the best known and nearest dark nebulae is the Coal Sack which is about 120 parsecs (400 light years) away The Gulf of Mexico area of the North American nebula is about ten times farther away *See* COAL SACK

While particle clouds which obscure stars must be reasonably large to be detected dark nebulosities seen against bright nebulae can be observed in all sizes Perhaps the best known example of this type of obscuring cloud is the Horsehead nebula which is located between us and an emiss n nebula (*see* NEBULA) Numerous mall dense clouds have been photographed with large telescopes Such objects called globules are often as small as 1000 astronomical units (10 ¹ km) in diameter (Fig 2)

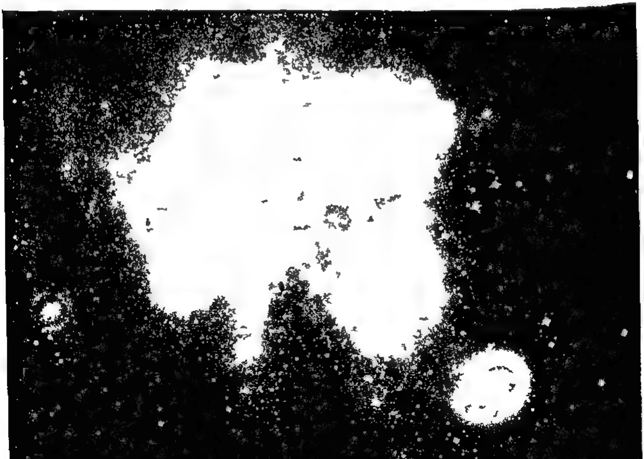

Fig 1 Reflect ebula s ted w th th Ple des sta cluste Th clo d w th bru hl k patte a compo ed of sm ll sol d pa t cles abo t 1μ i d am te R d at o p es e l p ob bly e po bl fo the t ak d app a ce of th lo d Photog ph d w th the Curt s-Schm dt U sity of Michiga

Fig 2 Part of th R ne b l NGC 2237 h ws m tu f l t mt llo p d g s. The d t g ss from th b ght t rs l the low left m f th ph t g ph i bl w g th l d g wey d t th som t m b k g fl gl b l Ph t g ph d d l ght w th th 48-n S hm dt t le f th M u t P l m Ob rv t ry

D k b l e m y ab rb a ywhe e f om only f w p e t f the l ght t ue f r m ny dif fu l d e p oj ted ag t th M lky Way t e t lly all th l ht mu t e r f r the d kest gl b les th ugh wh h ften no light n be e The l ght t a mitted by the le den e n bul e le t l bs bed m k g it p ble t t m n l t reg d g th natu l th pa t l n th bulae Th ab o pt n r es n hly th p e l f th w el ngth f th l ght d f om t d es of the b pt n pr p t f mall p rt cl L G H ns y a d J L. C t fo d it t h b ha gg t th t e th e y t l a g ng bo t l μ n di m te m t ll p rt l b t 10 m n d m ter a p odu s g th ab pt Be f th xpe ted la g p po t o f l ht l ment x t g t p e t m e bl t l leve that d k n b l omp d f e c y tal

Interstellar gas Oth g s th n that wh ch t n t thl n bul ha b n d t t d thr gh c b pti l h h an b b erved t th pect f d ta t t r l te tells l ne n b d t gu hed f m the stell t tm ph r c l by th i t m r wo d he a th y d n t h b t th am D ppl h ft th ta The t ng t l e e produ d g ally by met l h a l t m (b h the ut al and ngly n z d t) od um nd t n a f w m l ul f atu ha bee b erv d u h b n nd hyd o h d it ge The b rpt n l n i th l ght nd t ly m b da t

at ms n tal ly hydr g n are n t l served l ecau all xc t t on occur fr m tl e gro ind tates and no lin fr m s ich tra ti n appear in acce tl le regi n of the spectr m

The r d ati n d n ity in s t r tell r pa s ex tremely l w l we er the en rgy di tril iti n cor r p nd appr imately to that f a l ls k l lv at 10 000 K a ha l een d t rmined l y the am unt of i n zati n Thi t mperature and tl e relati l ne strengtl s l ad t an erage d n ity of int r stellar g s i our regi n f pace f abo it l at m/ cm³ Becau e th ga t larg ly hydrog n tl i valt e cor e ponds to about 10 g/ m

Beca se many int r t ll r lines ha e es tal c mp n nt when b erved with h gh l p r t n it kn wn that t t r tellar g t nd to a cum late t nd v d ial cl ud a h m ing with it own p a ate eloc ty t p ce Olte the velocities c r re pond t th f the spiral arm in which tl e cl ud are l e ted Thi mak it pos il l t u e th clo d to outl ne th l ape of a port n of tl e gal xy

The 1-cm hydr g n l n f freq iently ee in ab rpt wh n l d f neutral hyd og n ap p ar in fr nt f t ng t f r d emi t n

Interstellar particles In m ny w y the d tr buti n f th t t r t llar part cles res mbl th t of the g s Alth gh tl re a decided tende y f r th se p rticles t a umulat in cl ud they evertheles permeate all f inter tellar pa e within the piral arm f r gal xy All d tant ta appe s redd ned l y th mat rial and ar dimmed corr p nd ngly The int r t ll r bso p t as f dark n b l res appr x mat ly a the re pr al f the wa el ngth of the light Tl degree f redd n ng f tarl ght an be est mated f l acc tely by c mparing the l erved c l r w th that p ed ted f m tl e spectr m f tl tar H wever t is not so a y to determ n the t t l b pti at a g en wavel gth Ther f e mu l eff t h s been xpe ded t trying t fi d the r ti f tot l t sel cti e bsorpti The best e timate gge t that n th a erag in o r region f the gala y app xim t ly 50% f the l ght of a t r at a di tan f 1000 p secs (3260 light years) i ab bed If the gr prod g tl is ab rpt n are ce c y tals l μ n d amet the density f the i te st ll r p rt le mu t be t the icin tv f 30 p rti l /km 10 g m a alu wh h ab ut ne hu dredth that f t t r tella g s

Be au e f tl e h gh entrati n f i te tell r mat al towa d th plane of the gal xy the a er ag l f ab o ption p it d stance rap dly de rease m re d t nt ta s e b rved in di r t o r ght a gles t the gala t c pl ne Con e sely it e t em ly d fficult to detect d tion w th w el ngth l th n l μ c ming f om large d e n d recti ns) t the galacti plane Th zon f vo da ce whi h r pond ughly t the a ea oc up ed by th Milky Way t th t re g t th sky wh h e nt ally n e t agalac t obje t n b e b c u f the t rven g t lla m t r l

Intestine

The tubular portı n of the d ge tı e tract between th tomach nd the anu In man ıt c n ı ts f the small a d large ntestines The former s further dı ıd d ı to thr e maj r part the duodenum the jejunum ■ d the l um The duodenum 10–12 ın long begins ■ the pylo ıc phıncter of the t m ch and curve arou d the head of the p n c ea the r ght de f the upper abdomen It recen the duct of the biliary sy t m and the pan r as Th j jun m and ıl um are abo t 19 ft lo g nd form a mu h o led tube th t emptıe t ght angl nto the large bow l thr ugh the ıl o- cal f

The l rg bowel or c lon con ts of fi e parts th end ng t an ıe e descend ng and ıgmoıd eg s nd the termı l rectum which empt es th n l e al

All p rt of the ı te t ne are upported by mes- e es f ry ng ext nt, wh ch conta n an ex y tem of arterie e ns, lymphatics, and rves to the r ou reg n

The mı r op c structure f th ntestı e om an ın e glandular m c s conn ctı s bmu a mu cula at and n o t r r a of onn t e tı ue wh ch s co e ed n m t a by pe ıtone m

The f n t ry w th th egıon b t nclude ımarily d ge t n d ab rpt n of food e c e- n of wa t s d e t o of d gesti e ju e s See IGESTIV SYSTE ([E.G.S.Y.]

ntestine disorders of

h d of the ı t t ın l d o genit l de- ts a d l r mech n al d gen rat n l mm t ry a d eopl t dis rd r

Th mo t c mm g tal d f t Me kel i v t l m a pou h r t a s wh h pe ı t as the em ant f the fetal umb l c l du t Othe mall r m t a (a ı de el pm t a e n mmon Va c l lesı ı l d m s tere c th mbosı a blocki ■ f th art al supply r ve ou d aın g f the ı t t n by th mbu mbol It s f eq ntly c t d w th t aum he rt fa lu e r rte l

Comm n m h n al d d a e hernia the p t ■ f a loop f b w l th o gh a d f t o w k ss f th bd m l wall nd perito al d h r ult ng f om c t r ld p ıton ıı wh h oft l d t nte t al b t uct n Intu us ptıo n fr qu t d d seen ın t oft ınf nt ı h h o part f th t st t le- c pes t th t gment Th blood upply may b r d d nd bst u t n may s lt S m la res ft m f ll w lvul the twı t ng of a l op of t ı n ı wn me e ı ı talk th sup- port g f ld f p ı um.

Th th e d g n ■ e l w th th h ghest d n pr mu scid s and Wh ppl s d b t ll s ı l tı ely omm n The fi t m k d by f tty fo l m ll g bulky tool (t t rrh) d a m (pl ıty of oth I n c l symptoms The second ıs an ınborn deficıt of pan creat ■ secretion that cau es steat rrhea other symptoms includ sali ary a d sweat gland abnor mal ty and a thma *Whipple s di ea e* is a rare disea e of middle age ın which large fatty deposits accumulate in the intestinal walls and in tl e mesen teri s

Inflammations include non pecific and specific disea s (see ILEITIS PEPTIC ULCER) Tuberculo- si typhoid fever amebia ı ch lera and bacillary dy entery pecific infectı d sea es produced by ın a ı n of microorgani m may produ e intestinal lesi ns Variou chemicals and poison may also produ e ı flammations f the small intestine (en te ıtı l r of the large bowel (colitı) Ulc ratı e col tıs ıs a dı a e of unkn wn cause wh ch pro- duce ulc ratı ns of the intestine particularly the col n See AMEBIASIS BACILLARY DYSENTERY CHOLERA VIBRIO TUBERCULOSIS TYPHOID FEVER

Append c tıs ı the m t freque t pro ocatı n of urgery f the abd men It probably arı es from a combinatio of cau es, including infection and ob- struction f the l men and lso from para ıtic in festatio s The prompt surg cal removal redu es the n mber and everity of ■ mpl catio ene n t r d ın unt eated ases Append cit s ma be an ac te fulminating d ease r may persi t as a chr n c recurrent inflammatı n w th mu h scarring a d final bliteration f the l men

Maligna t tum rs f the mall inte tine are not common but the large inte tı e has a h gh ıncı de ce of arcın m s whı h account for 15% of all ance de ths each year in the Un ted States Oth r mal gn nc es are lymphoma Hodgkı s d ase mal gna t m la ma a coma and leuk m e ın filt atio s Se ONCOLOGY

Ben gn tum rs a e represe ted by polyp lipo- ma my m s a d fibroma d u ually occur in th c lon the mall ınt t ne rarely being invol d

D order of the p rıton um d th r abd minal rga s may di ectly r nd rectly ı volve th intes- tı e Other ma e cond t on xı t that m y affect th ntestıne any ystemic disord r may also pro- du intest nal changes r dy fun tion [E.C.S.Y.]

Inulin

A eserv p lysa chand ın some plants e pec ally those ı the f m ly Composı ., wher ıt ı found ın the root a d tube s of the dahl a Jerusalem artı ch ke a d dand l on Inul ıs nly sl ghtly solu ul l ın ld w te but r ad ly d ssol es ı hot w t r It d es not gı e a c l r eact on w th iodı h s l ttl r due ng p wer d s l rotat ry $[\alpha]_D^{20}$ -40 (ın wat r) Its m lecular weight ı ppr xı mately 5000 whı h c rr spond to hat length f ab ut 30 f ctof ra e res due It ı hyd o- l zed with a id r the enzyme ula from *As pe gillus niger* to D-f ct s The nulin m lecule ıs made up p ınc p lly of f uct furano e u ts lı ked β glyc s d cally fr m th hyd oxyl gr p on car bon 2 t th p ımary al oh l gro p n carb n 1 S e FRUCTOSE OPTICAL ACTIVITY POLYSACCHA RIDE

Starlight is not only absorbed by the particles in space but also scattered, giving the sky a faint luminous appearance. Such glow is one component of the light of the night sky; other contributors are air glow, or permanent aurora, and the integrated effect of large numbers of extremely distant and faint stars. *See* AIR GLOW; AURORA.

Polarization of starlight. A. W. Hiltner and J. S. Hall found that most distant stars shine with measurably polarized light; the total percentage polarization is never large, amounting at the most to a little over 7%. Because of a strong correlation between the amount of this polarization and the degree of interstellar reddening, there is no doubt that the interstellar particles produce the polarization. The planes of polarization of stars near the Milky Way have a strong tendency to be parallel to the galactic plane, suggesting that the interstellar particles are crystalline in structure and are oriented by a general galactic magnetic field.

Origin of interstellar material. Much interstellar gas has probably remained in the same state since its origin. However, a sizeable fraction of this gas must come from stars through the ejection of material by prominence and flare activity and from the shells of novae and supernovae. The interstellar particles grow through gradual condensation of the atoms and molecules. To grow a crystal 1μ in diameter takes about 10^9 years, neglecting the infrequent collisions of the particles. There seems to be little variation in the sizes of interstellar particles from one part of the galaxy to another, indicating the existence of an equilibrium state.

Formation of stars. V. A. Ambartsumian first pointed out that superluminous stars of high temperature, which cannot be very old because of the tremendous rate at which mass is converted into energy, are always found in clouds of gas and interstellar particles. Such associations are clear proof that stars must form from this material. Once a reasonably large condensation of interstellar gas and grains forms, it is not difficult to show how a star can evolve. However, the process of how such condensations form is not clear. Perhaps eddies in a weak magnetic field produce them. By blowing away the more tenuous material, radiation pressure would separate the condensations, producing the small dense globules which have estimated masses comparable to those of stars. *See* STELLAR EVOLUTION. [W.L.I.]

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Interstellar space

The space between the stars and other celestial bodies. For convenience of reference the space in the immediate vicinity of Earth is termed near space (*see* SPACE). The intervening region from Earth to the Moon is cislunar space; farther from Earth is interplanetary space. Interstellar space is strictly the region beyond the planets. This article deals with both interplanetary and interstellar space.

Nowhere in the universe is space absolutely empty; it is occupied by extremely tenuous matter, generally gas and solid particles from dust to meteors of 0.1–1 cm diameter, and large meteorite debris.

In the solar system at least 99% of the solid mass filling space occurs in the form of tiny particles of dust having diameters of 0.001–0.1 mm. The sunlight reflected from this dust cloud is visible as zodiacal light, showing a strong concentration near the plane of Earth's orbit (*see* ZODIACAL LIGHT). The dust is dark, its reflecting power being about the same as that of soot. Its total density is about 1 g/500,000 km^3. There appears to be a comparable amount of interplanetary gas, mostly completely ionized hydrogen, at least partly consisting of a continuous stream from the solar corona.

The meteoric and meteoritic component of matter in interplanetary space represents a much smaller mass, about 1 g/10^9 km^3. It is more conspicuous because individual meteors and meteorite falls are observable from Earth.

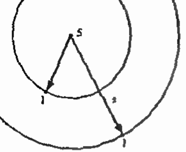
Comets with nuclei diameters of 0.1–10 km and asteroids (0.1–500 km) form the next step. During millions of years, meteor craters on Earth and on the Moon have been produced by collisions with these bodies. Unlike meteorites, they can be observed individually in space from a distance with the aid of telescopes.

Interstellar space near the plane of the Milky Way is filled with gas, mainly hydrogen, of an average density of 1 g/10^9 km^3. Everywhere it is accompanied by dust grains having diameters of 10^{6}–10 cm. The total mass of dust is about 0.8% of the gas, and the gas accounts for about 2% of the mass of the Galaxy (*see* GALAXY, THE). The dust obstructs light, but unlike interplanetary dust it is white and scatters light without much absorption. Gas and dust appear to be gathered into cosmic clouds 10–50 light years in diameter and with densities 10–50 times the average density in interstellar space. Interstellar gas is transparent; its temperature depends greatly on the radiation of nearby stars and varies from 10,000°C near hot stars (H II regions) to −170°C (H I regions). The temperature of the dust is everywhere very low, −250 to −170°C.

In the space between galaxies the density of matter is perhaps a millionth the density in interstellar space.

Interplanetary and interstellar space also contain primary cosmic-ray particles, which are atomic nuclei travelling with nearly the velocity of light and contributing a weight of about 5 g/10^{1} km.

Electromagnetic radiation, including x-rays, ultraviolet, visible and infrared light, and radio waves, travels everywhere throughout space (*see* RADIO ASTRONOMY). Visible light is emitted by stars, infrared radiation by the dust grains, and radio waves chiefly by ionized gas. [E.J.OP.]



F p t B em n g e gy f l t dy l
h e q l w t t s that l /l₂ = s /

ly f part l es a acuum u h a ra t e t m p ded the e ar n lect m g t field a d no m tu l t t a t Th t rm s o ed for tat field ta u h a th l w f avitat n d Co l mb l w n lect t t es

[w a s m]

nvertebrata

d ı n of th an m l k gdom wh ch ha no ta m tat I l ded u der th term In erte t a e ll th e anim l whı h l ck p n l c l mn b kb e t a t t Vrtebrat W th he x pt n f the phyl m Ch d t all othe hyla f the a bk gdom M taz a a w ll a th f th bk gd m P t zoa Mesozo and P ra zoa a m t b tes *S* MESOZO METAZOA PARAZOA VERTEBRAT

[C B C]

Invertebrate embryology

Th tudy f the de l pme t r mo ph ge es and gr wth f the n rteb ates The ame m e l p n pl of d l pme t pply t the rt b t th y d t th rteb t A tu lly mu h f the ba k wledg f mbry l gy h b en th es lt f t di th rt b tes A mm n ph m o th ı rteb t s th le s of a f e d d p de t f m the l rva befo e de lopm t mpleted The larv sy e n d r bly d ch te tı of th d ff ent m l gr ps

Th l f the ast maj ty of erteb t m l b g with th u n f n egg nd a p m t zo n Wh l these p duct ells kn wn llect ly g m t ould ha dly b m un l k e h th n mo t pects th y ha tw im p rt t f at es n mm n th g es n f a gl set f hr m m d th h ra t ı t e f be g t gg ed ll Th p rm t oo tr gg r es a form ha ge ı th gg rf ce wh ch e bl t t pe t at nd stimulate th gg Th l tte ı tr gg ed t r p nd to thi st m l t n by b g nı g the er es f mpl at d p oces es wh h d w the spe m toz t th gg br g togeth r the tw ... make up the d ul le t charact rı tic f the pe e c nd event ally e able thı fertilized egg cell to tra l te the heredit ry mes age int a faithful repl ca f the ancestral org n sy tem

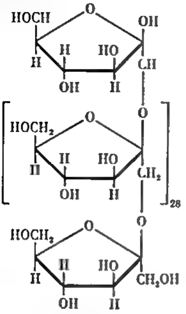
Aside from these t c mm n pr perties h w eve egg a d permat z a are highly d imilar While the n cl ı of both und rg the proce of me s s whı h pr pa m them for esentual uni n by reducing the r hara teri t c chrom some number t one half the c u es f preparati n f ll wed by their cyt pla m le d ın exactly oppo ite dı ec t n

Spermatogenesis Number mp etnes and mobil t are important f r spermat T ward th end the proces of sp rm t g nesi c n t of a t ge f cell proliferat f llowed by a period of pr g e ı e con e trat n and streamlin ng Th es e t l heredity det rm n ng mat rial f the chr m some s packed tightly int a tiny nucleu The cyt pl m f rms the locom t r apparatu u u ally a ı gle l ng flagellum with a c ntr le at ıt b e nd a *mitoch ndri n ne rly a w ll* an org n lle (ac osom) for pe trat ng th egg c er ng Excess cyt pl m ı fin lly dı c rded and the matu sperm t zoon (Fig l) ready t take p rt ın fertil zati n ı a elf ntained t ipped-down un t arry ng th h reditary message ın code nd pr vided with en ugh en rgy sour e t prop l it n a u t ined bur t of a tivity on its one-w y trip t ı n an gg f ıt species M llions upon m ll n of uch cell are produced ın the t tı whe e they rema n quiesc nt until th y are pawned *Se* SPERM CELL SPERMATOGENESIS

Oogenesis The gg ı designed f r a very dif fe e t r l It mu t c nt ın u ugh sub tan t pr ide stru tu al m te ı l for the f rm t n f a ll f simple org n f loc m t on and d gest n so th t th you g an mal an ec re food t arry on its further growth It mu t l cont ın en gh en rgy yield ng mat r al t pe f rm th w rk of d dı g the ıngle gg cell ı t body cell fr m wh ch au h o gans a be f rmed and to ynth ize the complex hem cal s b tan s needed t p o ide e h f the e new cells with a new nucleus *S* OOGENESIS OVUM

The egg th ref r is spe ial zed for large s z and p ot t n of its c nt nts with les c n rn f r numbers a d n n at all fo mot l ty In dd tı n t cyt pla m possesses int ns c capacitie f d f fer tı t o a d b ıld g act ordanc with the spec ficat s c ntaı d ın ıt chrom mes s th t spider egg always pr duces a pider and ne e a fly The fa t that the phy l ba e of thes apac t e h e so far eluded most f th effort d ted t wa d the d te tion ın n way ca ts d ubt on the ex t n e

Th r s rve build g and energy yı ld g ma te al a t ed the gg cyt plasm as m nute ph r s r pl telet f yolk a t bl lip pr te n h t Eg s a e l ge cell e n w thout thı ın rt mater al At the e d of th r gr wth pe od



Inulin

Hydrolysis of inulin with inulase or baker s yeast invertase produces about 1 5% D gluco e It is not certain whether this glucose is an integral part of the inulin molecule or whether it is a constituent of an associated substance which is hydrolyzed at approximately the same rate as inulin [W Z H]

Inventory management

Companies often invest some working capital in materials used in carrying on the business The quantity and location of these materials control the annual total of the expenses and losses for carrying inventory ordering material and running out of stock collectively called inventory expense Inventory management is the work of minimizing annual inventory expenses which usually maximizes the return on the inventory investment

One phase of inventory management is to minimize the quantity of material needed to conduct business This is done by standardization to reduce the number of different items that must be kept in stock by choice of plant locations by coordinating the number of products and models in the line and by extending the use of interchangeable parts and materials

Another step is to minimize the period that each item is kept in stock by scheduling and by choice of delivery lot quantity based on lengths of production cycles and forecasts of demand

Effective inventory management requires records of expenses costs and lo ses that come from carrying inventory arise from ordering stock and result from running out of stock From such rec rds one estimates the effects of changing deli ery lot quantities lengths of reserve cycles and quantities of reserve stock Re erve cycle is tl e interval between the scheduled or expected dates of deli ery and u e Re erve stock is material that i on hand becau e a reserve cycle i allowed in scheduling the delivery of material Delivery rati is the p r centage of deli eries made on or before th day the material is required

Changes are planned by finding what the expenses were for one set of delivery lot quantities and lengths of re erve cycle and estimating what the expen es will be for other condition Care must be taken to see that the data u ed in the calculations represent expen es that actually will change For example space costs are a part of the cost of carrying inventory but a change in the amount of material kept in stock may not change the space costs

The delivery lot quantities and quantities of reserve stock can be calculated by examining the effects of changes in the e quantities on co ts and profits The delivery lot quantities usually are economical when the related costs per year for carrying inventory equal the ordering co ts per year plus the average costs of stockouts per deli ery The amount of reserve stock usually is economical when the cost per year of saving one stockout per 100 deliveries equals the value that will be paid for this benefit The practicality of the figures obtained from these computations should be reviewed by someone familiar with purcha ing and manufacturing problems The feasibility of planning deliveries analytically (*see* LINEAR PROGRAMMING) depends on the accuracy of the available data including plant needs and vendor performance

Inventory management also includes in talling and operating a material control system which ensures that material is usually where it is required when it is required Material control includes developing a signal that material should be ordered to meet known or expected requirements ordering material notifying expediters of the need to expedite delivery and performing related ta ks These tasks include setting up and posting perpetual inventory records compiling records of quantit es used where u ed prices sources kind and quantities of material used to make the item a ociated items and similar information Material-control personnel also gather store proces and di tribute inventory management data Effective performance of inventory management aids a company in im pr ving its competitive position *See* INDUSTRIAL CONTROL [L J S]

Inverse square law

Any law in which a physical quantity varies with di tance from a source inversely as the square of that distance When energy is l eing radiated by a p int source uch a law holds provided the space l etween s ur e and recei er is filled with a n n di ipative h m geneous is tropic unl ounded medium (*s e* POINT SOURCE) All unl unded wa e be c me spherical at distances r which are large compared with ource dimen ion so that the angular int n ity distril ution on th expanding wa e surface who e area is pr portional t r^2 i fixed Hence the in er e q are law

Similar rea oning how that the sam law applie to mechanical shear wave in ela tic media and to c mpre i nal sound wave It holds stati

fert lized gg s l fted away from the surface after a sp rmat zoon h s entered and tr ngth ned by the add t o f mate i l f om the egg

Preliminaries to fertilization Sperm cell mu st omplet all the nucl ar and cytoplasm c hange nd be f lly mature bef re th y c n t ke part i fert l zati n On the other hand while thi s true f the cytoplasm f egg cell in m t pec s the nu l a p epar ti n for f rt l zati n s in mpl te he sp tm t n t ke pl ce Moreo er the deg ee of nc mpl t ne va i widely and apparently at andom

The mar n a el d *Nerei* sheds its eggs with th g m nal e cle ntact (F g 1b) Th en tr ce of spermat zoo mulate the egg t b g th ed ct on di i and th sperm p onucle s w its within the gg t pla m while th egg n cle s c rr es o t it p epar t on f ni n

Se h n eggs a e at the oth e treme in th s r pect Their reduct n d s on are ompleted i the *ovary* (*Fig* 1c) and the u o f egg a d *p rm p* ucl f ll ws immed ly upon sperm e try I many oth r pe ies me o s b g n h rtly befo th eggs are pawn d a d stops at one stage anoth r f the proc ss unt l the ent anc of a sp rmat z n s it goi g aga n (*Fig* 1d)

Rep od ct o am ng the invertebrates t kes place n a va iety of way wh ch differ w d ly fr m phyl m to phyl m F r e ample follow g pul t in *D o ph la* th rmatozo are st red i a spec al part f the female rep oduct e tra t and r l a ed a f w t time as e h ovum pas es down the d ct i b l d Th rmatozoa f squ ds re packaged n m ll b ndl s (*rm tophores*) Th se e pl ced by the m le ns ng ne of it a m wh ch is m d fi d for th pu p se in permatoph re recepta le the b dy f the female Th eggs ar fert l ed a they le e the v d ct and ar la d i gly n fing shaped mas es fixed to u d rw t bj ct

M t f the ech node m and many *mollu ks* c d n a nelids d el t ates shed their ggs n t mend n mber into the s a wat r whe e f rt l zat tak pl The you g larvae m t u ually fe d f r them l n In these ame gro p howev som spec es k ll r th y ng n se w te i ng ch mb a d po ket wh h e t a t lly with the body of the p re t a i m l Th s af the w th rthr pod su h as c ab wh h a ry th la se ma es fi ed to th bd m of th f m l d m b al e n wh ch th y g d el p f t me with the mantle h mb ll s wh th r the f rt l zed egg a thus p tected by th pa nt a mal l d z j lly m es l ath y ca f lly struct d b ood lls (b s b nt ng wa ps) i ply th wn nto th w t r ch egg n d pend nt un t cap bl f d l p g nt an dult w th t ny f rthe t h t n f m the pa ents

Fertilizat on u f rt lizat n n m y teb ates w th th pr d ct t a r f th f m) It wn ng ha t k n pl e n exp t t m l wh h a t well u d to d

or experimentally r produ cible it i hat lly s prising that the actu l proces ha been ol rved with the m cr sc pe in only a r latiy ly few pe cies The e are howe er a number of i vertel rat am ng the form wl ich hed their gam t int th sea in whi h it i po bl t add p rmat zoa t egg nder th micr cope and h r the j r ice of perm e try ery clearly In th m t fa or l l ca es the course f event within th egg a tl e tw pr nu lei un te and the *z g te proceeds* t und rg i s cce i d i i n and diffe enti ti n can be f l lowed Read micro c p cal l rvati n req ires em ll transparent egg wh ch are normally *ferti* li ed o t ide the body f the f male are a ailal le in l rge number a d remain fertilizable in the labo atory The egg of some s a urchin best fol fill these c ndit n and l a e pr ided much f tl e ava lable inf rmati n r lating t the f rtilizat n proce

The ea ur hin egg offers the f rther ad antage of ha i g c mpl ted it *redu tion d vi i ns* with i the o ary s that it s in a relati ely tal le tate *when it is spaw ed It also re p nds* perm entry *in certain easily rec gnizable ways* which fac litate tudy of the f rtil zati n proce As a resi lt it ha come to b g n r lly th ght of as a model for all fert l zat lthough it i actually a rather special ca

Th u fertil zed ea urchin egg (Fig 1e) i a sph rical cell abo t 90 μ in diameter s irr unded by n n isible layer of jelly abo it 30 μ thick It small pr n cl us l e eccentrically the cytopla m wh h i c owded with mall part les About half of these are y lk sph re the rest a e mitocho dri p gme t granules a d va ious other minute bodies wh e funct n is not yet well under tood Di ectly under th s rf ce membrane i a compact layer of sp ial gr nule 1 μ in diameter called cort cal nules (Fig 2a) El ctron m cr copy sh ws thes gra ules to be compo ed of at lea t two k nd of m teri l a d th y remain firmly in place und r centrifugal forces which mo other part clea t d ff rent part f the cell

The surfa e of thi cell is co red by a ry deli e te it lline memb an which li dir tly o er the l y r of rtic l gra ules When the fertilizi g sperm t zoo m k c tact with th s surf ce an impul e is tra mitted a und the egg from the p int f onta t The fi st detectable result of th s mpul a hange in the cortical gr nules wh ch g i app at the p i t f sperm attachme t and sw ps around th gg reach ng th opp site s de in about 20 e nd This ch ge on ists f a swell g f n of the c mp n nts of the granules cau ing th m to bur t a d s parat th vitelline m mbran fr m th of the cytopla m A c l lo dal sub t nc r lea ed into the spa e b l w the r i ed membra e take p wate and swells so that by about a m nute afte rm tt chme t the mem bran i free fr m th cyt pla m c s f ce all a und th gg (Fig 3a b)

While this oc urs the p rmat zoon i b ng drawn i to th gg By tl e tim the sp rm head

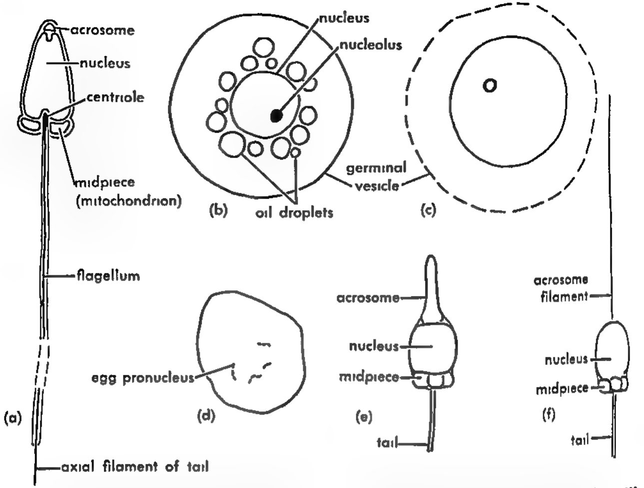


Fig 1 Spermatozoa and fertilizable eggs (a) Sea urchin spermatozoon (b) *Nereis* egg (marine annelid) with intact germinal vesicle containing a nucleolus Spheres surrounding germinal vesicle are oil droplets (c) *Mytilus* egg (marine mussel) germinal vesicle broken down but polar bodies not formed (d) Mature egg of *Arbacia* (sea urchin) containing egg pronucleus (e) *Mytilus* spermatozoa (mussel) acrosome intact (f) *Mytilus* spermatozoa acrosome reaction

when they have accumulated the full amount of yolk they are huge in comparison with the body cells of the parent animal No invertebrate eggs however achieve the spectacular dimensions of bird eggs The largest are found among the arthropods (crayfish eggs are 2.5 mm in diameter) while some marine animals have very small eggs (oyster eggs are about 65 μ)

During the growth period while the egg cell is actively synthesizing yolk and increasing the amount of cytoplasm it has a very large nucleus the germinal vesicle (Fig 1*b*) When it reaches full size however and this synthetic activity subsides the nuclear membrane breaks down releasing its contents into the cytoplasm (Fig 1*d*) The two successive nuclear divisions of meiosis follow but the cytoplasm instead of dividing equally pushes out one of the daughter nuclei each time as a polar body These two minute bodies have no further function in development The chromosome material left in the egg forms the egg pronucleus (Fig 1*c*) which is ready to unite with the sperm pronucleus The zygote nucleus formed by their union is comparable in size to those of the body cells

Polarity of the egg Many types of eggs show structural departures from radial symmetry which indicate that the unfertilized egg is organized around a bipolar axis one end of which is called the animal pole and the other the vegetal pole The polar bodies are given off from the animal pole and the egg pronucleus remains in this region When an egg contains conspicuous amounts of yolk it is usually concentrated in the vegetal half of the egg.

Egg membranes Since the eggs of invertebrates are often shed directly into the water of oceans and streams or laid to develop in places where they are exposed to the drying action of air and sunlight, they are always surrounded by a protective covering In some forms the eggs are laid in batches which may be enclosed in a leathery sac or embedded in a mass of jelly In other cases each egg has its own separate membranous case a layer of jelly or a more complex system of protective structures

If the young animal is to begin its development under exposed conditions as do many insects the egg is provided with a tough covering (chorion) which is impenetrable even to its spermatozoa In such cases there is a minute hole (micropyle) in the chorion near the animal pole through which the fertilizing spermatozoon can enter Among echinoderms the delicate vitelline membrane of the un

Ext nd ng in all d rect m   und thi po nt the ay soon re ch th c ll   rface (F g 3d) P b- ably a th re ult f th pu l e t d ltere by tl e r c ntinu ng lon ati n th   nter of tl e a ter con n n the p rm p nucleu mo es l wly t wa d the cente   f the egg At the   ame t me the egg pr ucleu beg n t m e (Fig 3) t wa d the   nte of the p rm a t r that   t ward the p rm p nucle s wh h s n w   bl a a lear phe e st ll   m hat maller than the egg pro u l Ten min t s at m t afte   pe m entr   e th two pr nucle l e in c   ta t (Fig 3f)   urr nded by th r y   f the p rm   ter These co tinue to el n g t c rry ng th apposed pron cl   t th cent r f tl   a d   te d t the m mbrane on all ides

The un n of th tw pr n cle (yng my) ma k th c mplet   f th f rt l zat n p ces   The tu t   form the zygote nu l u with th full c m plement of hr m somes and th d rmant e g ell h s b e   arous d to   t n m tion the er e   of h n es wh h will p du   a n w ea r him

A n umb r   f the   ents wh h ha   ju t been d sc bed r p ul   t   u ch   W th d ffer   t tim   l ed les nd allowa ce fo th indi idu l h a te t a of   h p   h wever these b pr c   es f perm   t y   ter l rmat n and ing my mak   p th compl x phenome on f th t l zati   ti n   n   r in all an m l S

ERTI IZATI N

S h a d er pti e pres t t n   gg t m ny uest on   bout what s   tuall g ng on n term f ll la a t n   d   t n On   h q es- t   f   x mpl   n th natu   f the   n ct b t ee   p rm t zoon a d e g   u lac   It s m   that n m   rtebr te the   r some 1 h   t   r tip f the p rm ell n lergoe a e pl   e   ct n at th egg urf ce wh h t ns- form   t   t a   rv l nd r fil me t (F   ) f) I at f   t som   a es an en mel k   ub t n   i l o l ed f m th   me whi h h   d   l ng d t   th   g m mb   Th e t   d   th t th p netr t n f th   g   rf   by th s fil m t ets r   th egg m h n   lly Wh th r t s l o ful   d aw g tl   p rm t zoon   d the gg yt pla m h s y t t b p o ed

Th   at   of the pec ficity wh ch en   s that gg w ll b ent r d o ly by   p m t   a f th   wn p ies h   l   l   th   bject   f   gt t   f   f es ar h   d ha   t ll   t r e ed   tho ughly   t fa tory   pla   t on Th   mech n sm by wh h   gg th t h   rec t d   p rm to- oon ejects ll l t   rr al t an th   p blem th t res t sol t n b t p rhap   m   d ffic lt d c e than th   nsw   t   a   f the   q e ti ns   r th   e on   t g th cytopla m   diffe en es betw   nfert l z d   d fert l z d   g

Cleavage Th   f rtil ed   g o   zyg te,   t abo t at   e t d id th huge m s of the gg t t many m ll   lls n rd r to r t e th   al rat   b t   n th   m   t of   le r and yto- pl m   bstan   Th   ne gy f   these   p ated m t es   mes f m th yolk   h h l   f rn hes t l   t p rt of the m t   l   q   ed fo   s   thes s of n w   cl   tructu es Du g th s l   g per od whi h comm nly occur dur ng th   fir t 12 h t rs   fter fertilizati n the l ls t m res   a   the clea   ge t g c ll ar   called di ide more   r les vn hro   u ly Generally clea age f ll w   one of es ral pattern   wh ch t   cl aracteri t   l r larg gr up   f animal and t   lten c rr lated with the am u t and m de l di tr l t   n of th   y lk

Whatever cle vag p ttern t f ll wed the plane of the fir t cleavage pa   tl r ugl the an m l pole When the   egetal r g   nta n   a larg   pr por t n   f y lk   le age t retarded in tl t area and the bla t meres tend to be l rg r than in th   ani mal pole r g   n

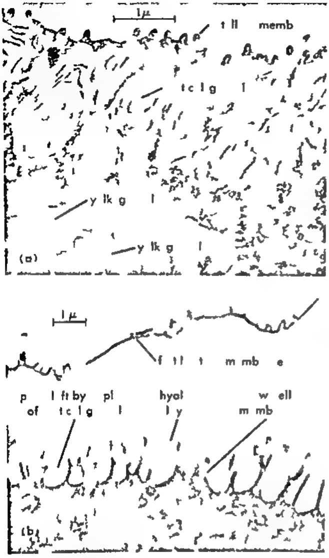
Sm ll gg   wh h c nta n l ttle y lk di i le com pletely and u ually   ery regularl   f ming a ma of   ell   that h w   pir l (m ll   k   Fig 4a b) bilateral (a   d   ns, F g 4c)   r rad al symm try (ech   derm   F g 4d) Some coel nt rates h w es   cl ave t to what app ar to be rand m m   es f c ll (F g 4)

Th   ery l rge egg of squid   ntain a gr at deal of yolk co centrated at tl   v g tal pol   Th   l av age fur ow   do n t c t   ll the way thr   gh thi p rt but restri t th   e   ct   ty to th   li ing cyto- pla m at the animal pol

In ect egg   also contai   a large   tore of y lk wh ch occ p e the c   t r f th el   gate ells, a d t   rr nded by   th n layer of li ing cyt pl m onta n g th   egg pr n iclea Following f til za t n th   lei al ne di ide and m e apart in the layer   f cyt pla m aft   ea h di t   n so that they d tribute them el   ll a   u d th   gg After nin   uch nuclea div   ns ha e take   pl ce (p odu ng 51? nu le l the cytopla m   lso cl a es t the n xt d vi t   f rm ng a   ingle lay r c mposed of   bout 1000 c lls surro   d ng th   entral y lk ma

Blastula stage Am ng all the   ert b ate f m xc pt the n ct   the res ilt f   ix to t   le es y l   ag cycl   s th f rmati n of a phe   (l las- t la) c mpo ed of   mall cells wh ch l e n   ingl omp ct lay r ar   nd a   nt l c vity (l la to- coel) If th   egg has conta ned r lati ely l ttle y lk the bla tocoel   t rather larg   (F g 4f) while t may b   ery m ll if the egg includes mu h yolk (Fig 4g) and   l ttle more than   lit n the m d bla t l (F g 4h)

Gastrula stage Th   e d of th   brief bl tula stag oc   r when the pr   ess of ga t lation be- gi   In t   mplest f rm thi c n i t   n an in d nting (i vag nati   ) of th bla tula w ll in th eg tal   g n (F g 5a) Mea wh l   ll di i n s g   g on t dily a d ance th larv   h s as yet no way f tak ng in   l d food f m tl e   ut ide all th f rm cha   es wh h   d ring th s p r od ar   mpli hed with the m t ial or gi   lly p e nt n the f t l ed gg The only ad i t n is w t r (bl stoc l flu d) a d   h d ss l ed sul tan   m tly   lts f o   th   ontent   s   n   t th   gl th   ll membra es A   the bl   t m becom   malle   d the bla tula wall   po d t gly thi   ll a   p o ded t e t   d th y ge- t l nd   tat n nt   a p   ket (F g 5b) With the app ra   f thi   tru t   (p min   d est e tra t) the l rva bec mes two-lay ed t



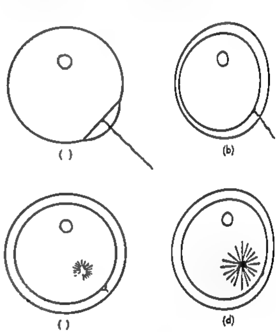
Fg 2 ( ) Electro m crog aph of s ct o through face of nfert l ed s a ch n egg (*Hem t t s*) (b) Electron m c og ph of fert l d *H m t t s* egg surface

has entered a small bulge of hyaline cytoplasm the fertilization cone is f rmed and the perm tail gradually disappears into the cytopla m through thi cone (Fig 3c)

The separated meml rane continue to expand for a minute or two During this period the ul tance relea ed from the cortical granule and di lved in the fluid immediately surrounding tl e egg unites with calcium from the ea water and form a com pound which accumulates on the inner urface of tl e lifted membrane This i now called tl fertili zati n meml rane and the added material strength en it o remarkal ly that it i al le to r si t di s l ing acti n of all kind xcept that exerted l y a part cular enzyme which the sea urcl in larva synthe izes when it i ready to hatch

The new egg surface replacing the elevated itel line meml rane follows the highly irregular c nt ur of the pocket which formerly held the c rtical granule (Fig 2b) The second component f the granule which wa left l el ind in these pock t gradually moves outward witl in a few minute after f rtilizati n Taking up calci im from th medium th ub tance f rms a hyaline layer cl e to the egg surface which is without a bounding membra but is supported by delicate cytopla mic pro ections This layer holds the bla tomeres together after cleavage and acts as a protective co ering after the larva has left the fertilization membran

While the changes are occurring at the urface the sperm head is carried a short way into the egg cytoplasm For some three minute it i possible to distinguish it among the granular inclu ions in very transparent eggs After thi and while part of the tail is till outside the e g the perm nucle begins to swell and can no longer be recognized in living eggs Within two more minute a halo of hyaline rays begins to appear in thi region This is the sperm aster (Fig 3c) formed by the egg cyt plasm under the organizing influence of the perm centriole



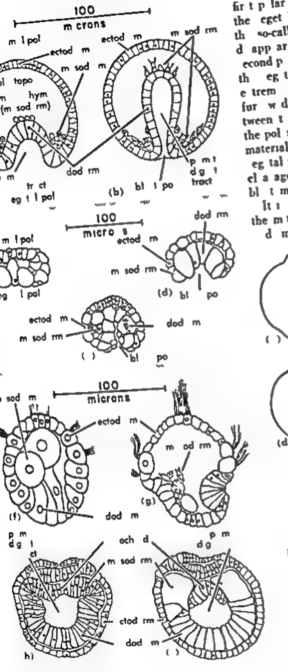
Fg 3 Fe t l t on of th s a chin egg (a) Forty o ds aft i m at o Sp m h ad beg ng to e te cytopl m f t l z t o m mb a e l ft d round p m e t a c po nt (b) Th e mi ut fte l em no to F t l t o m mb a f ee a d gg rface F t l zat co fo m d (c) F mi t s Sp m a app g e d of p m t ll abo t to t egg (d) S mi t s Sp m a t e l gi g mo i g toward c t f gg f rt l z t co d pp ari g (e) Eght m t s Egg p cl m g tow d c ter f p m a t p m p cl i bl (f) Te mi ut Sy gamy c mpl t p m f ll g cytopla m

ed ry car fully o th t th ir life his- f lly k wn A f w of these w ll be out n f ll w ng ct ns

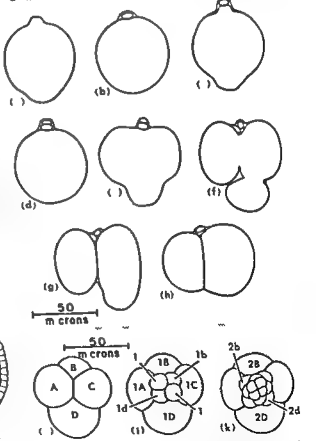
MOLLUSCAN DEVELOPMENT

Fertilization and cleavage The eggs f *Myt l* the c mm n m el are fertil zal le ju t after the germinal icle br aks down (Fig 1d) A the fir t p lar l ody i gi en off fr m the animal pole the eget l urface f tl e egg bulges ut t f rm th so-called polar l be (Fig 6a–d) The bulge d app ar h rtly t reapp r at the time f econd p lar body formati When the egg cl a es th eg t l cyt pla m i egregated into a m re e trem polar l le (Fig 6e f) and th clea age fur w d de the rem ning material equally be- tween t o l la t me e Th t i t n f rm ng the pol r l be d appe r reti rn ng tl polar lobe material to on f th bla t me es (F g 6g,h) The eg tal mate i l i again s gr gated at th second cl a age nd aga m xed with ne f th f ur bl t me es

It i ha act ri t f thi type f clea age that the m t ti pi dles l e a lant i the l la t m res d m reo r reg la ly change the direct n f

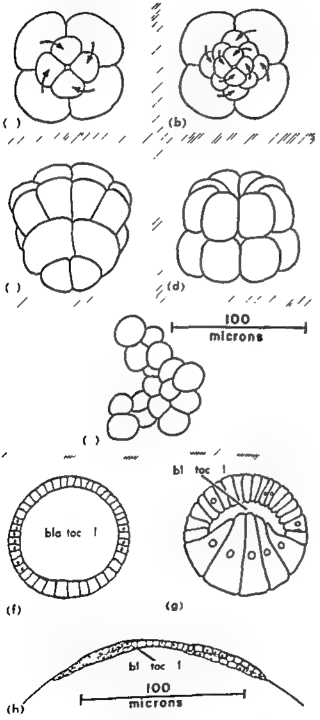


Fg 5 G t l h d l rv l m d m f m t ( ) E ly tag y lky ggs. (b) L t tag y lky gg ( ) L t tul y lky gg f th sn l Litt (d) E ly g tr l i y lky gg f Lit t ( ) L t g t l y lky gg f Litt (f g) P t ll th l mp t m sod m f m t cti th gh t f bl tul d t h ph larv (h) C ss sect f Amph mbry mm d tely ft g l t ( ) C f Amph m



Fg 6 M tu t d ly l g l th m l *Myt l* ( ) F rst p l body b i g fo med at lm l p l p l l b t g t l p l (b) F rst p l b dy mpl t ly t d d p l l b w thd w (,d) S d p l b dy f rm t (,f g) F rst l g (h) Two-c ll t g ( ) F -c ll t g (j) E ght-c ll t g f rst q rt t f m m (1 1b 1c 1d) (k) S t -c ll tag w th th q rt ts f m m

an outer layer the ectoderm which will later produce the nervous system as well as the outermost body covering and an inner layer the endoderm from which will be formed the lining of the functional digestive tract and its associated organs and glands As the primitive digestive tract extends into the blastocoele its opening to the outside becomes smaller and is known as the blastopore



Fg 4 Symmetry of cl avage patte ns and in rt brate blast lae (a b) Spi al clea ag (c) B late al cle ag (d) Rad al clea age ( ) l g la clea og (f) Sea u ch n blast la R l t ely u fo mly ized blastome es and la ge blastocoel (g) A el d bla t la Blastom re at getal de la g yolky; small bl to coel (h) Sq id bla t l Blastome s l m im l pol reg on o ly sl tl ke o no bl toco le

A modification of this process of endoderm fe mation occurs among some species having larg yolk filled vegetal blastomeres (Fig 5c) The s all actively dividing cells of the animal pol reg a spread down to cover these more inert bla tomer (Fig 5d) which become the endoderm and la er form the digestive organs while the overlying ect derm leaves a small opening in the vegetal regy which corresponds to the blastopore (Fig 5e)

Mesoderm formation At this time the fir t few cells belonging to a third body layer th mesoderm make their appearance by slipping from the ectoderm layer into the blastocoele The e early mesoderm cells are of a primitive sort (mesenchyme) pos essing p eudopodia and often mo ing ab ut freely between the ectoderm and endoderm In sponges and coelenterates no more highly organized middle layer is formed even in adult animal but in the other phyla the so-called true mesoderm is endodermal in origin either being formed by successive divisions of a cell which originally belonged to the endoderm (Fig 5f g) as in annelids and mollusks or separating off from the primitive digestive tract as in *Amphioxus* (Fig 5h i)

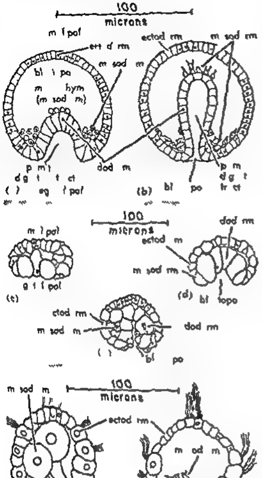
In either case this me odermal ti sue spreads o between the ectoderm and endoderm and in al phyla more advanced than the flatworms spl t through its center into an inner and an outer layer The cavity thus formed within the mesoderm is th true body cavity in which the various internal or gans lie The outer layer of mesoderm become closely applied to the inner side of the ectoderm forming body wall muscles and other supportin layers while the inner layer of mesoderm surround the endoderm with layers of muscle The organs circulation excretion and reproduction as well all muscles and connective tissue are eventuall formed from this me odermal layer

Later development So far it is po sible to sum marize the development of invertebrate animals a group but beyond this point each subgroup f lows its own course and these are so widely di e gent that every one must be considered separatel Meaningful generalizations are not even po sib within a single class in s me cases as atte ted to l tl vari us modes of d velopment occurring amo the Insecta s me of which proceed directly fr egg t adult form while others go through an ela orate series of chang s See INSECT PHYSIOLOG INSECTA

In very many species there is a sharp break th life hi tory when the larva after pa n through a numl er of m rph l gical pha es whi lead from n to the next with a steady increa e iz and complexity al ruptly forms a whol n s t of ru lim nt ry a l lt rgans which tak o er t vital functi n Thi metam rpl o i repre nts t nd of th larval p i d Th tiny animal which produce is f r tl f r t tim re ognizal l a t ff pring of its p rent

F r more or l arl tr ry r a ns tl devel m ntal proc of c rt in in rt l rat f rm l a

b en tud ed very caref lly that their l fe histor e ar fully known A f w of th will l e ut l d n the f ll w ng e ti ns

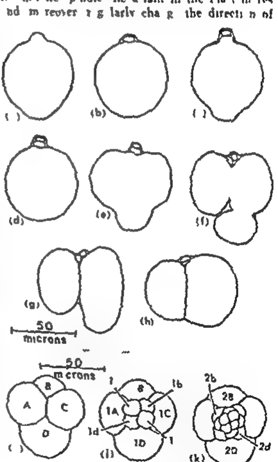


Fg 5 tr lot d l rv l m od m f m ( ) E ly g n y lky egg (b) L t g In y lky gg ( ) L bl tul l yolky egg f th l Litto (d) Ea ly g t f l y lky gg f Lit ( ) L g y lky gg f Lit (f g) P t ll th l mp t m od m f m t o ct o th gh of bla t) d h ph l rv (h) C sect f Amph mbry imm d ly ft g tul ( ) C sect o f Amph m bry som wh t l t

MOLLUSCAN DEVELOPMENT

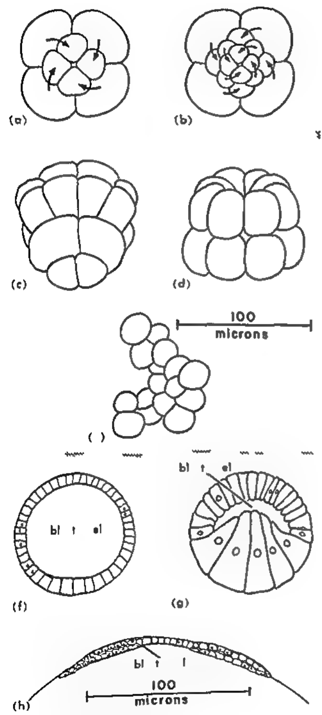
Fertilization and cleavage The eggs of *Mytilus* the common mu el are fert l zable ju t after the g rminal ve i le bre k d wn (Fig 1*d*) As the first p lar body s gi en ff fr m the animal pole the vegetal surfa e of the egg l ulge o t to form the so- alled polar lobe (Fig 6*a–d*) The bulg di appe h tly t r app ar the tim of nd pola body f rmat n Wh n the egg clea es th v g t l yt pla m i s gr gated into a m re e t em polar l be (Fig 6 f) and the clea ag furrow d id the rema ng mate i l e ally betw en two bla t me e Th c n tu ti f rming the pol lobe d app ars ret rni the polar l be m t rial to ne of th bl t me es (F g 6*g,h*) The eg tal mat rial i aga n egr gated at the se ond cle age a d aga n mi ed w th o e f th f ur bla t me es

It s characte i tic of thi typ of cleavag that th m t tic p ndle lie a lant in the l la t m res nd m reover r g larly cha g the directi n of



Fg 6 M t nd e ly l ag in th mu l *Myt* ( ) F rst p l body be g f rm d at m l p l p f be t eg t l p l (b) F rst pol body mpl tely t d d p l l be w thd w (d) S c nd p la b dy f m t o (*f g*) F t l g (*h*) Two-c ll t g (i) F c ll st g (j) E ght-c ll t g first q art t of m me s (1 1b 1 1d) (*k*) S te c ll tag w th th qu t t of m o- m e

an outer layer the ectoderm which will later produce the nervous system as well as the outermost body covering and an inner layer the endoderm from which will be formed the lining of the functional digestive tract and its as ociated organs and glands As the primitive digestive tract extends into the blastocoele its opening to the outside becomes smaller and ■ known as the blastopore



Fg 4 Symmetry of cl av ge patter s a d i e te brate bl stula (a b) Sp ral cl av ge (c) B lateral cleavage (d) R d al leavage ( ) Irreg lar cl a age (f) S a rch blast la R l t ely un f mly si ed bla t mer a d la ge blastocoele (g) A l d bl st la Bl st meres at eget l s d la ge yolky sm ll bl sto coele (h) Squ d bla t la Bla t me ln a imal p l reg n only sl tl ke o no bl sto el

A modification of this proce of endoderm fo mation occurs among some species having larg yolk filled vegetal blastomeres (Fig 5c) The mall actively dividing cells of the animal pole regi n spread down to cover the e more inert bla tomeres (Fig 5*d*) which become the endoderm and later form the digestive organs while the overlying ectoderm leaves a small opening in the vegetal regi n which corresponds to the blastopore (Fig 5e)

Mesoderm formation At thi time the fir t few cells belonging to a third body layer the mesoderm make their appearance by slipping from the ectoderm layer into the bla tocoele The e early mesoderm cells are of a primitive sort (me enchyme) pos essing p eudopodia and often moving about freely between the ectoderm and end derm In sponges and coelenterate no more highly organized middle layer ■ formed even in adult animal but in the other phyla the so called true me derm is endodermal in origin either being f rmed by successive divisions of a cell which originall belonged to the endoderm (Fig 5*f*,*g*) ■ in ■ nelids and mollusks or separating off from the primitive dige tive tract as in *Amphioxus* (Fig 5*h* *i*)

In either case this mesodermal tissue preads out between the ectoderm and endoderm and in al phyla more advanced than the flatworms plit through its center into an inner and an outer layer The cavity thus formed within the me oderm is the true body cavity in which the various internal organs lie The outer layer of mesoderm become closely applied to the inner side of the ectoderm forming body wall muscles and other supportin layers while the inner layer of mesoderm surround the endoderm with layers of muscle The organs c circulation excretion and reproduction as well a all muscles and connective tissue are eventuall formed from this mesodermal layer

Later development So far it is po ible to um marize the development of invertebrate animal a group but beyond this point each subgroup fo lows its own course and these are o widely di e gent that every one must be considered separatel Meaningful generalizations are not even po ib within a single class in some case as attested b the various modes of development occurring amor the Insecta some of which proceed directly fro egg to adult form while others go through an ela orate series of changes *See* INSECT PHYSIOLOG INSECTA

In ery many species there is a sharp break the life history when the larva after pa through a number of morphological phases whi lead from one t the next witl a steady increa e size and c mplexity abruptly forms a whole ne set of rudimentary ad lt organs which take o er tl vit l function This metam rpho ■ repre ent tl end of the larval period Tl e tiny animal which produces i f r the fr t time recognizal le as tl off pring of it parent

For m re or le arl itrary rea on the develo ment l proce e of certain in ertebrate form ha

U haped w th the mouth and anu epa ated from ea h ther o ly by the f ot there ı a udden pe riod f unequal growth n th tw des f th larva o that th anu ı mo ed ar und t pen on ıts neck (Fig 7) Fye and tent le ha e alre dy b en f m d and fi ally the young animal dı a ds ıts c l um be ng elum nd tak s up the adult hab t of r p g bout on ıts foot

SEA URCHIN DEVELOPMENT

Fertilization and cleavage The fi t and econd [a a pla s d ide th fert l zed egg (e F g 3) nt f ur q al bl stom res ınter ect ng ea h ther at r ght gl s th ough th nimal ege- tal x Th thi d l a e cuts thr ugh tl e e four bl t mere h z tally The f rth clea age pla d vide the upp r four cells nto ıght equal

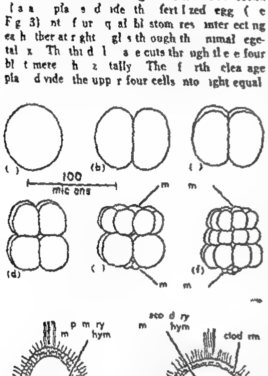


Fıg 8 Cl g d g st l t th a h ( ) Zyg t (b) Tw -c ll ı g ( ) F -c ll ı g (d) E ght-c ll st g ( ) S t -c ll ı g (f) Th rty two- ll g (g) Veg t l g f bl tul flatt ed p m ry m hym c bl ı (h) B g g f g t d ry m hym c ll p p g bl t oel (ı) P m t d g t t ct d pe g b g g f p le f m ı o (j) L t g l f om de

s zed mesomeres and the low r gr up ınt f ır ery mall mı m res at tl e vegetal p le and f ur large macr meres (Fıg 8) Tl e e 16 l la tomer are each d ıded about equally at tl e fiftl cl avag f rm ng 3 c ll l ut tl e eight micromere fa l t dı ıde at the xth clea ag so tl at ther are 56 ın stead of 64 bla t eres at thıs tag lly r m ıng certaı of these l la tom res (ı ch as tl micro- m res) and f ll wing the later devel pment ıt ha been f und that the eıght m cr meres of the 5(cell tage gı r t the fir t gro ıp of m en hyme cell the rıng of e ght cell ju t abo e them pro- du e me enel yme and e d derm and all tl oth bla t mere f rm ect d rm

Blastulation The l l ı m re *continue to d ıde* s cces ıvely f rmıng the h ll w pl e e f the l l tula tage ll the tenth cleavag (Fıg 8f) eacl of th thou a d o l la tom re ha de el ped a c l um, nd the bla tı l h s also secr ted en ugh hatchı g enzyme to dı sol e th fert l zat m m brane Aft abcut 12 h urs f devel pm nt at 20 C the larva begın ıts free wimming per od

Gastrulation Shortly afterward the larva lon gate som wh t t wa d the an mal pcle where a tuft f l ng ımm bile cılıa appe r and fl tt n n the vegetal d J t bef re ın gınat beg ns the cell de c nded fr m the eıght mıcr m res l p t of the getal bl tular wall ınt tl e l l toe l (F g 8g) form ng tl e primary mesenchyme ll

Th ga tr l t ge beg ns about 20 l ur after f rt l zat n whe the ent r f the getal wall bulges ı ward (F g 8h) Mo t f th c lls wl h form th s pocket will be ome *endode m l ut the e re al o* ome m e chymal ell *among them* (ec dary me e chyme) wh ch w ll devel p p e do- pod a that t t h acr s the bla t coele and mak ın c ntact w th th pp te body w ll *direct the* ınwa d xpan ı n f tl primıt ve digest e tr ct (Fıg 8) A the d er n the p m ry mesen chyme cells re bu ld ng c lc reous pı ules with l m t k n from the e wate The skeletal r ds t d ın three d ection f m two point be ıd the bl st po and a th lengthe th dete m e tl e ch racte tıc h pe f th uc eed ng l rv l st ges (Fıg 8j)

Pluteus stage f th pl t us tage (F g 9a b) m uth p n ng ı f rmed wl th tıp of the f m t e d ge tı e t act ı n the body w ll The t act beg n t *funct on* nd the bla topore ch ged ınt a an s th larva ı able f r the fir t tıme ı tak food from t d S e DEU TEROSTOMI

Metamorphosis D th m nth wh h tl e l rv p nd pl t us tl e body crea e mark edly ın s e and t o mo p s f rms r add d In prepa atı f r met m rph s a t cture c lled the ecl nu rud m nt f ms the b g nıng f the dult g n ystem W th n a l tı ly hort t m mo t f the larval b dy rp r t d nt thes org ns wh h a e c gn zable as those f a yo ng a chın It m tamorphosis is com plet wl ıt ea ts off the u usable p rt of its larv l k let n (Fıg 10)

their slant by 90 at each division so that a spiral pattern of blastomeres results Such spiral cleavage is found in the mollusks and in the flat round and segmented worms

Since the animal vegetal axis is easy to recognize in such eggs it has been possible to record the course of cleavage very accurately and to deter mine the role of particular blastomeres in normally developing embryos The four cell stage blastomere containing the polar lobe material is designated as D and proceeding in a clockwise direction the others become A B and C (Fig 6i) At the third cleavage these divide very unequally (Fig 6j k) into four large vegetal macromeres (1A 1B 1C and 1D) and four micromeres at the animal side (1a 1b 1c and 1d) *See* CELL LINEAGE

Blastula stage After two more such unequal di visions the resulting 28 micromeres have formed a hollow blastula with the four macromeres 3A 3B 3C and 3D at its vegetal side These then extend into the blastular cavity where their descendants will form the digestive tract except for one of the D daughter cells produced at the next cleavage 4d which is set aside as the mesoderm mother cell (Fig 5*l*)

Trochophore stage During the succeeding cleavages some of the cells develop cilia the blas tular symmetry becomes bilateral instead of radial and the micromeres extend down almost to the vegetal pole thus covering the macromeres except at the small opening of the blastopore After 24 hours of development the cilia are organized into an encircling girdle and an apical tuft at the a i mal pole and the larva now called a trochoph re begins its free swimming stage (Fig *7a*) The blastopore is shifted forward by the fa ter pro liferation of the ectodermal cells of the other side (Fig 7*b*) and then closed but the larval mouth is later formed at this place (*see* PROTEROSTOMIA) Behind it the endoderm forms a stomach and a narrow tube gradually extends from this to make the intestine The anus forms later in the place where the intestine reaches the ectoderm

At this stage a group of ectodermal cells is form ing the shell gland which will secrete the hell (Fig 7*c*) Two small protuberances will unite and develop into the foot and a pair of elongated pit beside the mouth will form the balancing organs The 4d blastomere has cleaved into two cells l cated on either side of the mouth which are gi ing rise at this stage to two rows of me oderm cell called the mesodermal bands

Veliger stage Within a week the hell gland has grown and begun to secrete the shell and the foot is projecting prominently The stomach increases in size and bulges into the shell cavity and cell from the ends of the mesodermal bands form mu cular attachments for the stomach and e ophagus The girdle of ciliated cells (velum) enlarge and the rudiments of a nervous system including eye cups appear near the apical tuft The larva is now called a veliger (Fig 7*d*)

Metamorphosis Following further development especially of the alimentary tract which becomes

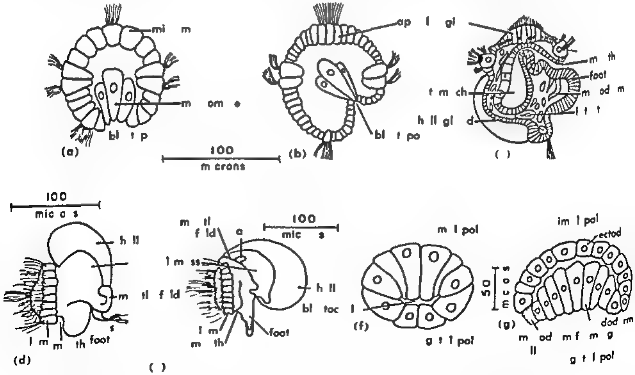
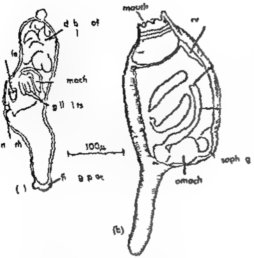


Fig 7 Stag s I the dev lopme t of *Pat ll* a d gast l t o in a tu lcate (*a*) Lat bl st la of *Pat lla;* macromer s being co e ed by microm es blastopore at veg tal pol (*b*) Ea ly t ochopho e of *Patella;* blas topore h fted forwa d ( ) M tu ed t ochopho e larva of *Pat lla* (*d*) V lig la of *Pat ll* ( ) L te el ge stage of *P t lla* Twi t g of body h s ca d m tle f ld a d p to f an f rwa d a d tu n d h ll about (*f*) Late bl st la of t lcat mbryo (*g*) B g i g of g t lat o l t lcat embryo



Fg 11 M t m rph t t ( ) Beg g f m tom ph (b) Yo g d lt

mt t e f g t f a w th th e t derm t op n s a nu a d f rm a t ma h and a li e l ke gl nd

A culat ry sy t m wh ch wa started d ring the t dpol t ge d el p a m cular heart. F ur n w pa of gill lits p n s to th pharynx The e l t d ide a d g t furthe ws of mall r lit Th epr duct rg ns re f med from tw m sses of m derm e ll fy g ne r th ph r ynx. These dev l p nto an ary nd t stis

[J C D]

Inverter

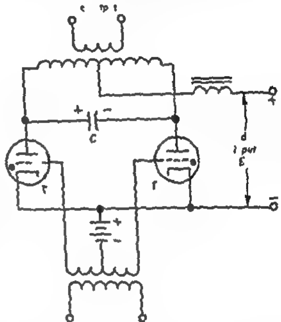
A dev ce fo n ert ng di ect e r e t (d) s t alt at ng u r t ( ) F r low power q e me t t may be n electr mechan l v b ator wh ch u es nta ts n a b atıng a mat r to r ers th pol ty f th d rect urr nt at a rat o resp d g to the d s d a fr q en y (s e VI BRA OR) Such in t r re ed in utomob les t ba g th torage b ttery lt get 115 volt alter nating u nt f op at g a p bl c add y t m t pe ecord r o the a equ pment i th car Th e all d el t m i ert r A el tric r t i ng m h n th t e rt d s ac i l all d m e t (e CON ERTER YNCHROVOLS) Th type f i rt r s lt n u ed c ft For la g r p w r req r m nts the r v r al f p la ty t r g l r int rval s d e w th thyr t gm t o tt l t o d e th t d t h e nta t g p bl m

[J R]

Thyratron inverter A p tely ated pa all l thy tr nv rt i tt h n in the fig r A ntr l s g al bta ned f m n ext rn l applied t the grid n a symm t al on ect o h wn

N glect ng th t be d p nd a m ng that th right h d t be T h s fi ed th f ll d upply lt g E pp a the p t C w th th l ft h nd id ha ged po t ly d cated D r ing the ne t half-cycle when th control v ltag on tube T_2 bec mes positi e en ugl T_2 fires. This cau es the voltage $-E_4$ to appe r acr s T_1 and T_1 i extingui led Then C i cl arged through T_2 t th v ltage E_4 but with th oppo it polar ty to that how

In the foll wing half-cy l T fires T_2 i xt n g i hed nd C recharg through T_1 to the polar ty shown in the figure Th abo e cycl of events is r peated w th a frequency equal t that of th con tr l s gn l



A ep t fy-e t d pa ll l thy t i vert l t

If the lo d is res sti e a d he y the utput volt ag has a square wa efo m For a l ght resisti e load the output h a tria gular wa e hap For an indu tiv load a sinusoidal wa ef rm output may b obta ned

It i po ble to l m nate the extern l ac contr l signal by obt n ng the grid ltage from the out put pl te c cu t. Such a c nfiguration i called a s lf e c t d in ert S e OSCILLATOR

[J MI]

Involute

A t rm appl ed t a urve C that ts at ight ngles all ta g nts f a curve C Ea h rv C ha i finit ly many i v l t s and the d tan e betw e corre spo d ng p t f any two in l t s is co tant If $x = x(s)$ w th $s = 1\ 2\ 3$ a e paramet c eq t ons of C with par m ter r length a C all inv l tes C f C ha param t equ ti n $Y_i = (s) + (k - s)x'(s)$ with $= 1\ 2\ 3$ wh e $x' = dx_i(\ )/ds$ w th $i = 1\ 2\ 3$ a d k de ote n a bi tr ry c nsta t L t l ngth of tr ng be nc de t w th a curve C w th o e e d fa t ned at a po nt P f C If th st g i unw u d man g ta t, the th d of th tr n i c n i l t C of C

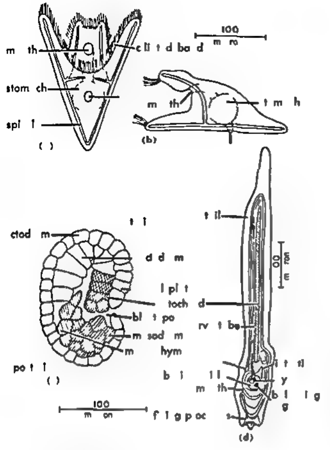


Fig 9 (a) Pluteus stage of sea urchin larva ventral view (b) Side view ( ) Section through tunicate gas t la (d) Tadpole stage of t cate l rva

TUNICATE DEVELOPMENT

The fact that certain structures characteristic of vertebrates and found in no other invertebrates *appear during the larval life of the tunicates forms* the basis for giving these otherwise unprepossessing animals their high status at the top of the invertebrate subkingdom and makes them especially interesting from the evolutionary aspect

Fertilization The eggs of the tunicate *Styela* begin meiosis as they are laid going as far as the metaphase of the first reduction division where they stop until they are fertilized The spermatozoon penetrates *the thick chorion* enters the egg at the vegetal pole and stimulates it to proceed with meiosis While the polar bodies are being given off cytoplasmic streaming segregates the cell components into a yellow pigmented region a clear yolk free region and a gray yolky mass It is possible to recognize these differently colored materials later in development and determine the role of each in body layer formation

Cleavage The first cleavage divides the egg into similar blastomeres Because of the arrangement of the colored cytoplasm it bilateral symmetry is already visible The 16 cell stage consists of two layers of eight cells each (Fig 4*h*) with the yellow cytoplasm contained in four of the vegetal cell At the stage with about 40 cells a blastula is formed The prospective ectoderm making up its animal side consists of thick columnar cells while the future endoderm cells at the vegetal side are relatively flat (Fig 7*f*) This difference is reversed before gastrulation begins (Fig 7*g*)

Gastrulation The gastrula is formed by the movement into the blastocoele of the vegetal side cells followed by an overlapping growth of the prospective ectoderm Within this enveloping layer the yellow cells produce mesoderm the other vegetal cells form endoderm As the gastrula develops the surface layer anterior to the blastopore (Fig 9*c*) forms neural tissue which is organized into a brain and spinal cord while the mesoderm beneath it forms a notochord a precursor of the vertebral column characteristic of vertebrate animals This notochord elongates as the axis of a tail and the larva hatches from its chorion and begins a free-swimming stage

Tadpole stage During this stage (Fig 9*d*) the tadpole acquires an extensive but nonfunctional digestive tract two pairs of gill slits (also characteristic of vertebrates) a cerebral eye and a balancing organ At its anterior end it has three papillae with which it will fix itself to a substratum when its short tadpole stage ends

Metamorphosis When metamorphosis begins (Fig 11) the tail ectoderm contracts strongly *bending and breaking up the notochord* nerve cord and tail muscles which are consumed by phagocytes The chin region next to the organ of fixation elongates greatly carrying the mouth upward A new nervous system replaces the larval one The

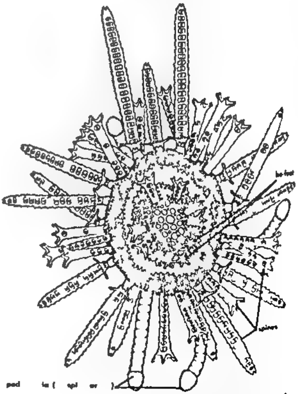
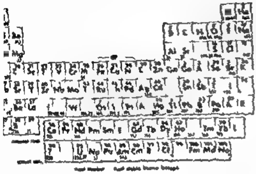


Fig 10 Y u g chi o d (P o ella japo c) after met m pho i (F m K Oka ak o d J C Da M to m ph s of part of larv of P o ella japo ca M t a s d dollar Bi l B ll 106 83–99 1954)

I d n ı tial to h gh r anum l a d ı d zed alt (ro ta n od m or pota ıom ı d des) ı w del u ed t a u e an adeq ate d etary s pply of iod ne S NUTRITION THYROID LA D

T mp rtant d tr al u of iod ne are n (1) ph t g aphy wh r l er od d ed s a n t tu nt f fa t gh t aph c film emul ı a d (2) the dye ı du try wh re ı d e ı a n t tu nt f a umber of imp rtant dy See DYE OTOGRAPHIC MATERIALS SALT (FOOD)



Occurrence I d n w d ly but rarely n ıgh n t t d ne er ı l m t l form th g e t atı n n the th c u t ha e n e tim ted t be 0 3 pa ts p r mill on (ppm) ı d the nt at n ı se wat r s about 0 05 ppm Th m t imp tant r e l iodi e th od um n tr te dep it f Ch l ı whi h odı s a al m ı d te ntrat o of b t 01% d e by w ight A ıl mport nt r of d ıs tan l w ll b ınes f Californ a and Jap wh e n t at s n th nge f 50–100 ppm f d In th e br od ne o ur th od d n I

Recovery and production Mo t f the w ld ı l pply m f m th Chilean depo ts So l t o tan g the d t e du l w th sod um bı lfit to p t t the ı dı *The pre p t t d d p r fied by s bl m t m*

$$2N IO + 5N HSO \rightarrow I + 2N SO + 3NaHSO + H O$$

I th U ited St tes *bst nt al p rt* of the od umptı ppl d f m d m t ıl b ı Th p p l c e m thod in e n l d t f tl ı did n t f ee od with hl d m al f th latile *od ne* fr m ı l tı w th a t eam f a Th od abso bed n I t d d ed r hydr od d th lfu d de

$$I + SO + 2H O \rightarrow HI + H SO$$

Thı fot ı hl nated t p pitat f od whi h ı pu fi d by tre tm t w th n nt ated sulf d

In th t od h bee l t d f m ert f m f wed th e h f wh h c t n p ı 0.5% d d by w ght nly a m n amo nt f od e bt ı d f m thı u

Physical properties Only one ı t pe f ı l e occur n t rally th t f ma n mber 127 (53 pro t n 74 neutr n) O er 22 a tif al isot pes l a e been pr pa ed f whi h the mo t important ı l with a half lif f 8 day Thı ot pe ha f ind con d a f l ın radı a tı tracer w rk S TRACER RADIOACTIVE

Th mol c lar f rmula of odı ı I₂ n the ld l quid and ga eou tates alth gh at tem peratu es of se ral hundred d grees C dı socia t n of the molecul nt atom becomes appr ı able

I d ne ı moderat ly sol ıble in a numl r f n n pol r sol ent ıch a ca bon t tr hl ride and aliphat hydr carbon Thes lut n p es the ame hara teri ti v l t l r a the vapor h w ng th t in these l ents iodine reta n ıt d at m c tructure Iodine ı m t lul l in ar m t hydro c bon a d ygen c ta nı orga ıc sol ent such a al oh l and ester with wl ı h the iodine form molecular complexes Soluti s in aromatic hydroc l ns a r d nd lution in xyg n co ta n g sol ents are l rown Alth ugh iodin ı only ı ghtly sol l l water g ı g l rown l ı t n tı xtrem ly ol l l in ol ıtı ns c nta ng ol bl odides becau e of tl e f rmat n of deep h wnt bl ck c mplex polyiodide on

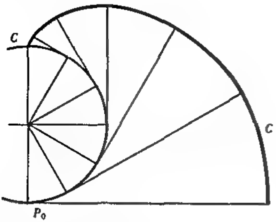
Chemical properties In its l m cal pr p rties dine es mbles the the m mbe s f th h l gen fam ly H wever iod ne the lea t electronegati e f tl e hal g n tl at ıs ıt exhibits tl e le t te d y to equ re electr n to c mpl te its oct t f le e elect n A a re ult it ı the le t re a t hal g n tl e easie t to oxidı e and f rms the w ake t bond with th mor electropo ıt e elem nts

Iod ne f rms comp und w th all of the eleme t x pt the n ble e lfu a d el *nium It* t d r ctly with t elem nt xc pt c rbon t gen o yge and me of tl e n bl m tal *I di e f ea ts* s d th th r l l gen w th n mbe of o gan comp nds In general tl e act ns w th iod are l s ıg us and may n t p oceed t an app eciabl xtent u les a y hy dr g n iodide HI which ı f rmed is cont n ou ly rem ed Am the typical a t ns f iodine w th o gan mpou d a e th react on with b t tuted a mat cs to form aryl od de the e t on w th c rbo yl compou ds to d t the carbon adj t to th ca bonyl d tl add ti n to mul t pl bo d of n t ated hyd oca bons

Iodı ı aq eou s lut n ı edi ced t iod de ıon I by good educ g agent su h a s lfu

Som import t physical propert es of iodi

At m w ght	1 0 91
Spec f gr vity 0/4	4 910
M l po t C	113 6
B l g po t C	18
H t f f n, cal/m l	3770
H t f po t l/m l	9970
Sol b l ty w t g/1000 g (0 C)	0 9



An invol te C of curve C

By varying the length of the tring all involutes of C are obtained See ANALYTIC GEOMETRY

[L M BL]

Involutional melancholia

A severe depressive reaction occurring at the time of the female climacteric and during the corre sponding age period in men It is characterized by symptoms of sadne anxiety guilt and low self esteem similar to the depres ed states of manic depre sive psychosis Patients often have hypo chondriacal and nihili tic delusions a coml ina tion with paranoid reactions is not infrequent Usually such patients do not exhibit any intel lectual deterioration (see MANIC DEPRESSIVE PSY CHOSIS)

The etiology of the disorder is unclear Endocrine processes eem to be of importance but detailed e idence for such an a umption does not exist Or ganic mechanisms are probably similar to the depre sive states in manic depre ive psychoses Psychological ob ervations have shown that mo t involutional depres ions react to real and imaginary depri ation of love and e teem with evere depre ion Often a deprivation of a imilar type can be detected in an analy is of the patient relation hip with hi mother during his infancy and early child hood

In the differential diagno is organic reactions pre enile di orders paran id tates and chizo phrenia need to be con idered The differential diagnosis of neurotic and reactive depre ion may be very diff cult (see PARANOID STATE SCHIZO PHRENIA)

Electric convul ive treatment tranquilizing drugs and psychic energizer in coml ination with psychotherapy are the u ual meth ds of treatment In mil l ca es electric c nvul i e treatment can and hould be avoided H pitalization i u ally indi cated and the preventi n of suicide and self de tructive behavior i particularly important See P YCHIC ENERGIZER P YCHOTHERAPY TRANQUIL IZER

[F C R]

Bibli graphy J R Ewalt F A Strecker and F G Ebaugh *Practical Clinic l Psychiatry* 8th ed 1957

Iodate

A negative ion having the formula IO_3 and de rived from iodic acid HIO_3 Some alts uch a $KH_2I_3O_9$ and $KH(IO_3)_2$ indicate that the a id may exist as polymers of the ion indicated by the empirical formula Sodium and pota ium iodates are the mo t important salt and are u ed in med cine

Iodates occur along with $NaNO_3$ in Chile salt peter They are prepared in an electrolytic reac tion similar to that for the preparation of chl rates or by oxidation of iodides with chlorine

The iodates are more table and are weaker oxidizing agents than bromates and chlorates See BROMATE CHLORATE IODINE

[E E W R]

Iodide

A compound which contains the iodine at m in 1− oxidation state and which is derived from hydr odic acid HI

The chemi try of iodine and its ability to f rm covalent and ionic iodides is very imilar to the properties de cribed for chloride See CHLORIDE

In comparing the iodide ion with the other hal de ions it should be pointed out that the iodide are more covalent are the l est reducing agent of the group and form the lea t stable complexes The aqueous olubilities of the metal iodide are mu h the same as the chlorides but in general a l ttle lower In organic olvents the order of olubil t i frequently rever ed Bismuth and mercuric iod des are only slightly oluble Iodide ion coml ine with free iodine to form the triodide ion I

Sodium or pota ium iodide i added t table salt to prevent malfunction of the thyroid gland Silver iodide is used in photographic film and papers

Iodide can be detected in olution l y oxidizing it to the free element with chl rine It impart a vi l t c lor to the ol ent when extracted into carb n tetrachl ride See COMPLEX COMPOUND HALIDE HALOGENATED HYDROCARBON IODINE PHOTO GRAPHIC MATERIALS THYROID GLAND

[E E W R]

Iodine

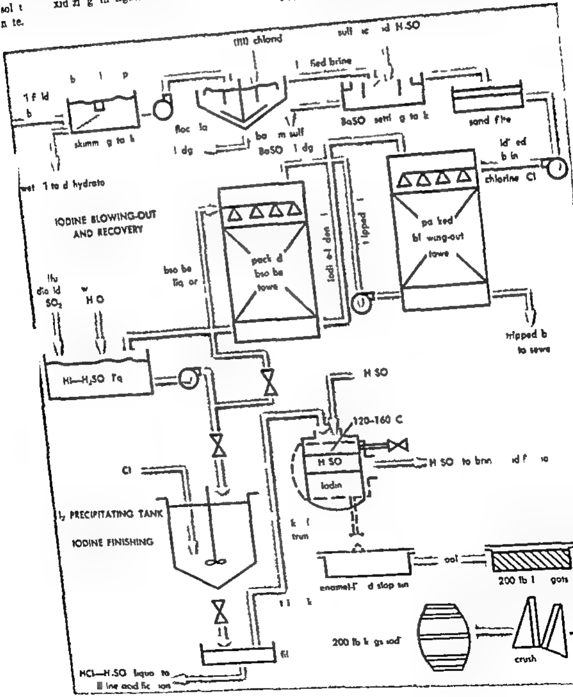
A nonmetallic element that is the next to-hea iest meml er of the halogen family group VIIa of the periodi tal le Iodin I atomic numl er 53 exi t under ordinary c ndition as a grayi h l lack sol d cry tal of wh h po e a mewl at metallic lu ter Heating the olid yield a i let vapor See HALOGEN ELEMENTS

Uses Pharmace itical and th erapeutic u e a ount for o er half of th e i dine con um ed at th pre ent time O e of the principal such u e i in anti epti l ut a larg numl er of prep arati n ntaining io l n mp und al exi t f r the tr tment f ari d or l r and a aids in x ra pro dur In r ce t ye r i di c mp un l ha c me into e f r h nfe ti n of drinking water See ANTIMICROBIAL AGENTS ANTISEPTIC

? ri d c a d exi t m l t on both as th p a d H IO ■ d the met d *HIO* Th occur a e f th pa form with od ne but not with sm ll h logens i att ibuted t the la ge iz th iod n at m whi h ca acc mmodate more t m d it lf S lt f both form are k wn d a ge ally p ri gly l bl in water Th l d dec mp e n heat ng t oxygen and io- l t Th pe od tes ar powe ful idant in id sol t xid zi g m nganous n t permanga n te.

Compounds of iodine-organic There are tw mportant l es of rgan c comp und c ntaining iod ne the od des and th e in wh ch the iodine i in a pos ti o idat n stat

Iod d s The impl organic iodide resemble the other h l des in th ir pr p rties The carbo iod e bond i the w akest f the hal gen-carbon bo d a d the ■ ■ od des a e the lea t tabl and th e m t re cti Beca e of th l e v iod ne ■ m th iod des are al the den est and the lea t ola t le Alkyl odides are prep ed by the reacti n f



P od ct f iod

dioxide SO_2 or hydrogen sulfide H S The thiosulfate ion $S\ O_3$ is oxidized to the tetrathionate ion $S\ O_6$ by iodine and this reaction serves as a basis for the analytical determination of iodine The iodide ion is easily reoxidized to free iodine by moderately strong oxidants such as ferric iron and bromine It is slowly oxidized by oxygen in acid solution

$$4I \ + O_2 + 4H \ \rightarrow 2I_2 + 2H_2O$$

In the presence of iodide ion iodine reacts with starch solutions to form an intense blue color which is often used to detect iodine in very low concentrations

Iodine is hydrolyzed only slightly in water to form iodide and hypoiodous acid in which iodine is in the 1+ oxidation state

$$I \ + H_2O \rightarrow I \ + HIO + H$$

However in alkaline solution the above reaction goes completely to the right because H ions are removed to form water The hypoiodite is unstable and especially in strongly alkaline solution disproportionates further to produce the iodate ion

$$3IO \ \rightarrow IO_3 \ + 2I$$

The oxidation of iodine or iodide in alkaline solution with strong oxidants such as hypochlorite also produces hypoiodite and iodate

$$I \ + 3ClO \ \rightarrow IO_3 \ + 3Cl$$

but excess oxidant will convert these species into periodate

$$IO_3 \ + ClO \ \rightarrow IO \ \ + Cl$$

In acid solution oxidation of iodine with strong oxidants such as chlorine permanganate and iodate will produce first iodine monochloride ICl in which the iodine is assigned a 1+ oxidation state

$$5HCl + 2I_2 + IO_3 \ \rightarrow 5ICl + 3H_2O$$

Further oxidation will convert the ICl into iodate

Compounds of iodine inorganic Iodine forms useful and important compounds with hydrogen metals the other halogen elements and oxygen

Hydrogen iodide This compound is a colorless gas with a boiling point of −35 3 C It dissolves in water at 10 C and one atmosphere pressure to the extent of 70% by weight The solution is known as hydriodic acid Gaseous hydrogen iodide can be prepared by reaction of hydrogen and iodine vapor over a platinum catalyst but is most easily prepared in the laboratory by the reaction of water with phosphorus iodide

$$PI_3 + 3H\ O \rightarrow H_3PO_3 + 3HI$$

Iodides The metallic salts of hydriodic acid are typical saltlike compounds with high melting points Except for the silver lead copper(I) and mercury(I) salts which are insoluble they are generally quite soluble in water

Potassium iodide mp 680 C, solubility in water 144 g/100 g at 20 C is also readily soluble in methanol Commercially it is the most important compound of iodine It is generally made by treating iodine with potassium hydroxide to form the iodate and iodide and then heating to decompose the iodate to iodide

Some iodides such as titanium and zirconium tetraiodides decompose to the elements at high temperatures very high purity zirconium metal is prepared commercially in this manner

With the nonmetallic elements iodine forms typical covalent compounds such as NI_3 NH_3 PI_3 and AsI_5 which possess low melting points and considerable solubility in organic solvents

Iodide ion forms anionic complexes in solution with a number of metal ions and in many cases salts of these ions have been prepared for example, K_2HgI_4 $KAgI_2$ and $Cs\ SnI_6$

Compounds with other halogens The simplest compounds of iodine with other halogens are binary ones such as IBr and ICl which are known as interhalogens These are low melting solids with halogenlike properties Iodine also forms two stable reactive fluorides IF_5 and IF_7 the former a colorless liquid the latter a colorless gas at room temperature

A number of metal trihalide compounds such as KI_3 $CsICl_2$ and CsClIBr are known They contain a linear trihalide ion with the heaviest halogen in the center Related to these compounds are the polyiodides (I_3 I_7) the anions of which can be thought of as complexes of free iodine and the iodide ion They form stable black solid salts with the larger cations and compounds such as KI_9 have been prepared

Compounds of the 1+ and 3+ oxidation states Aside from the interhalogen type compound the unipositive oxidation state of iodine also exists in compounds of the type $I(py)_2NO_3$ and $I(py)_2ClO$ which contain the I cation complexed with an aromatic amine (py = pyridine)

Although 3+ iodine is not known in aqueous solution compounds such as $I(NO_3)_3$ $I_2(SO\ )_3$ and ICl_3 can be made by oxidizing or chlorinating iodine in the absence of water

Iodates and periodates The most stable and well known of the positive iodine compounds are the iodates (5+) and the periodates (7+) which can be prepared by oxidation of iodine or iodides in alkaline solution Iodic acid HIO and periodic acid H_5IO are stable white crystalline solids which are quite soluble in water Heating iodic acid produces iodine pentoxide I_2O_5 also a stable white solid which reacts with water to reform iodic acid Except for the salts of the alkali metals and magnesium most iodates are only sparingly soluble in water Acid solutions of iodates are strong oxidizing agents being reduced to iodine or iodide ion The solid iodates are fairly stable to heat but decompose eventually to oxygen and either the iodide or the oxide plus iodine

on exchange

chem l act i wh h m b l hydrated i ns t sol d re ch ged q al t f r equi l nt ns f l k ch ge sol tion The sol d h an p fish tlike tru t re d the m b le s lec n lly n utral ze ch rged r p te t lly harged gr ps tta hed t th sol d mat x c lled the i h nge Cat excha ge urs when th fi ed ch rged gr ps (funct al g up) of the ex h eg t a exch nge occ s when the imm b l zed f tio al group e p tive Io e cha g sed f wat soften ng wate demin e l zi g parat n of s b t ces, and pu fi a t f h m cal

Eq l b a f -exch act r usu lly p e ed by th g n ralized q atio

Catio e change

$$aB^{+b}_{( )} + bA^{+a}_{( )} \rightleftharpoons B^{+b}_{( )} + bA^{+a}_{( )} \qquad (1\ )$$

An on exchange

$$B^{-b}_{( )} + bA^{-a}_{( )} \rightleftharpoons B^{-b}_{( )} + bA^{-a}_{( )} \qquad (1b)$$

with the rrespo di g ma et o xp es n

$$K_{AB} = \frac{[B^{+b}]_{( )}[A^{+a}]^{b}_{( )}}{[A^{+a}]_{( )}[B^{+b}]_{( )}} = \frac{[B^{-b}]_{( )}[A^{-a}]^{b}_{( )}}{[A^{-a}]_{( )}[B^{-b}]_{( )}} \qquad (2)$$

he e b kets d te the conce t at s f th h gi g o c pe ies A d B (glect g t v ty co ffi i t ffect f mpl c ty) a a d b pres t th r ch ges d d gn te the res (r h ng r) and sol t pha a d A e espo d t the ne el g eq l b m ta t. S e EQUILIB IUM CHEMIC L

D ff e n ft n e t b tw n the d t b t of v u i betw e th old d l q d pha es (th t K l es d ff f s l ct d p r of ns) U ually the d ff ce an be l ged by lec t ely mpl g i t l t n d by p t g th -e cha g ea t m y times Th tech q ch g c l r matog phy s th b f m y n k g pa t pr d that e mpl yed b th lyt l h m t Th ele- m t to b p ted a bed f m lut n a w b d t th t p p i f i ha g es l m d th w hed d w th c lum (l ted) by p g a electi mpl g ag t th gh th l mn u til p t n ll esed The n l g e t f e h n pe ted m y t mes by th p t n a d u mb ati w th th eff t f the mple ng t lt i the p t l the indi f l el m t nt b d n th l m S CH O ATOGR PHY

Oth mporta t ppl to f h g at ft g d the d m n r l zat n f w t l th fi t ppl i l m m gnes m d th u des bf t mp t es h ged f r d m i d g p l ti f th t th ugh n e h g es n l mn th and m f m In th ec d ll o mp t es t ed w t a em ed by e h g f

hydrogen a d hydroxyl ion du ing pa ge f th w ter necessi ly thro gh at and ni n e cha ge re m i the acid and l a e f rm

Zeolites Th e are natural cl y m ral which hib t io -e ch nge properties These mater al ha an open th ee dimen nal n tw k tructure (the al mino- ilicat skeleton) c tai ing reg lar ch n els t imb be wate Cat n wh h ne trali the ex es neg t e charges on their kelet n dif fu e i and t of th wate onta ed in th i ni form i te tices f the zeol te cry tal duri n xcha ge re tio

The ex hange cap c t es of these materi ls are ally expres ed a the numl r of mill equi ale t of c t per 100 g f d y material whi h are ex hange ble in n t l l ition The change c p te a well as thei c p b l ties f r ex hange differ con d r bly I the m mpact str t es exchange is limited t the smaller uni le t hyd ated a d n m n ta ce n change can occur I the ca e of rthocl (f ld spar) K O Al O 6S O f r example th p tas m ns are impr so ed d ailal le for x hange

Oth mpl cating f tu es in zeol tes e their t b l ty in ac d lkaline sy t m the pres ce f d ff r t tes with ry g bi d g strengths d rates f e ha g and th un n com p s u

Art fi l zeol tes of well-defined compo tio e now manufa tured with p fectly form inter stice f c t oll d dime ns a d with reg l rly d st b ted cha ged sites which demo trat q i v ale t o ch ge beha i F a d cus i f the mat als ee MOLECULAR IEVE

Other t r t g inorg n c n-e ha ge *mate-* l w th both at d a on-e change p per t e h bee pr p red E mpl s of th e com pound a e zi co m pho phate a d zi c um o *ide whi h* when pr p red by pre pit i n fr m sol t on a d d ed t le ated temper ture be ha at nd ni excha r pe ti ly P e mably th p ecip tat f p lym e st tu t n soluti o g vd s n tw rk with fix d r d l h g M bile i within th n t work n tral ze th ha ge

Ion exchange resins Thes a e m d up of thr e d m al rg c tw k n l d ng ha ged o p t ti lly ch rged gr p wh ch ar e t l zed by mobil n f *pp te charg* Fr ed m f th m b le r ter to m ma d t f th r i p ded by w ter m bibed b th resi on imme n an q eou s l t Th w t pen the e t tu e perm t t g d ff i f ons to and ut f the e w t (g l) ph ed g h nge

M ny atu l p od ts e h b t at o x h ng p p rt F r e mple the ll co t nt of pl nt i h a t ed b i h g tru t bee se f th p n of rb yli ac d g p Othe d c nt f nd a eth r l s lfate g (—C—OSO N) e t n aw ed a bo-

the corresponding alcohol and either HI or phosphorus triodide PI_3

$$3ROH + PI_3 \rightarrow 3RI + H_3PO_3$$

Methyl iodide which is prepared in this manner is a colorless liquid bp 42 5 C d(20/4) 2 28 It finds some use as an alkylating agent

Aryl iodides can be prepared from the hydrocarbon iodine and nitric acid

$$6C_6H_6 + 3I_2 + 2HNO_3 \rightarrow 6C_6H_5I + 4H_2O + 2NO$$

Iodobenzene which is prepared in this manner is a yellow liquid bp 188 6 C mp −31 4 C d(20/4) 1 83 It can be used to prepare organic compounds of positive iodine *See* HALOGENATED HYDROCARBON HALOGENATION

The alkyl iodides are the more reactive reacting with hydroxyl ion to give the alcohol and iodide ion

$$RI + OH \rightarrow ROH + I$$

and with amines to alkylate the nitrogen atom

$$RI + R\,NH_2 \rightarrow RR\,NH + HI$$

Positive iodine compounds A number of compounds are known in which iodine is formally in a positive oxidation state These compounds are characteristic of iodine alone among the halogens and occur only if an aromatic or olefinic group is attached to the iodine

The first group known as iodoso compounds has the formula RIO They are formed by oxidizing the corresponding iodide with strong oxidants such as fuming nitric acid They are soluble in alcohol but not in water are good oxidants and are stable at ordinary temperatures Treatment with HCl as well as chlorination of the original iodide produces related compounds the iododichlorides $RICl_2$

A second group of compounds is the iodoxy compounds RIO_2 which are prepared by oxidizing the iodoso compounds with hypochlorite The iodoxy compounds have properties somewhat similar to the iodoso compounds

If benzene is reacted with iodine pentoxide and iodine in concentrated sulfuric acid diphenyliodonium bisulfate $(C_6H_5)_2IHSO_4$ is obtained This reaction is general for benzene derivatives and the products are typical ionic salts The iodonium salts of many common anions have been prepared as have the hydroxides which are strong bases Diphenyliodonium chloride $(C_6H_5)_2ICl$ a white solid sparingly soluble in water has found some use as a disinfectant

Biological importance of iodine Iodine is widely found in both plant and animal kingdoms Because it occurs in most plants in only trace concentration it has not been possible to decide whether iodine is essential to plant nutrition However in many cases additions of iodine do stimulate plant growth

Iodine is essential to higher animals because of its relation to the thyroid gland Iodine absorbed by the body is converted in the thyroid first to 3,5-diiodotyrosine and then to thyroxine both of which are iodine containing amino acids Both compounds are secreted and transported to the tissues. See BROMINE CHLORINE FLUORINE IODATE IODIDE IODOFORM PERIODATE [M F O R.R.CR.]

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Iodoform

A yellow hexagonal solid with a penetrating odor also called *triiodomethane* CHI_3 *Its specific gravity is* 4 08 and melting point *119 C It is prepared* by the action of iodine in a basic solution (NaOH) on ethanol or acetone or by the electrolysis of an alkaline I_2 KI solution in the presence of ethanol or acetone It serves as a qualitative test for the

$$\mathrm{CH_3{-}\underset{\underset{OH}{|}}{\overset{\overset{H}{|}}{C}}{-}}\quad \text{and}\quad \mathrm{CH_3{-}\underset{\underset{O}{\|}}{C}{-}}$$

groups It is soluble in organic solvents and insoluble in water It has weak bactericidal properties and exerts antiseptic action when applied to raw wounds because of the liberation of free iodine its chief use is in ointments for minor skin diseases It is toxic when taken internally *See* ANTIMICROBIAL AGENTS HALOGENATED HYDROCARBON [E H H]

Ion

An atom or group of atoms which by loss or gain of one or more electrons has acquired an electric charge If the ion is formed from an atom of hydrogen or an atom of a metal it is usually positively charged if the ion is formed from an atom of a nonmetal or from a group of atoms it is usually negatively charged The number of electronic charges carried by an ion is called its electrovalence The charges are denoted by superscripts which give their sign and number for example a sodium ion which carries one positive charge is denoted by Na a sulfate ion which carries two negative charges by SO *See* ATOMIC STRUCTURE AND SPECTRA CHEMICAL BINDING

Salts are usually composed of orderly arrangements of ions which are not free to move easily in the solid However when the salt is fused or dissolved in water *the ions become free and* when an electric field is applied to the salt in solution the positively charged cations move to the cathode and the negatively charged anions move to the anode At the electrode the ions lose their electric charge This process is called electrolysis *See* ELECTROLYSIS IONIC CRYSTAL SALT (CHEMICAL) VALENCE [T C W]

m t Catio ic pecies a e selecti ely transfer ed thr ugh th e t on ex hange membrane and ni , n c spe ies ar lecti ely t n ferred thr ugh the n n ex ha m mbr n to achieve th s res It F r a d cu o of th s pa t on t ch que s e DIALYSIS

Rece tly insol ble l qu d c t o and anion ex ha ge s h e been prep red nd stud ed The i n xcha ge behavi r f the e an l g of the resins d s r b d above i remarkably similar to that of the r cro s-linked elati es. S cc ssf l application of th selecti e exch nge pr pertie fo affect g separations by solvent extraction techniques is a certa nty

Ion exclusion By this pr cess the penetration of soluble electr lyte into the re n gel phase is p e nted Th d stribution of electrolyte between tw phases in th s ase the re in and external solu s g en by the Don an equ librium

$$[A^{+\nu}]^{b}_{(\,)}[B^{-b}]_{(\,)} = [A^{+\nu}]^{b}_{(\,)}[B^{-b}]_{(\,)} \qquad (3)$$

whe e the symbols are th ame a employed in Eq (2) This b h v or of ion excha g re ns is d ri d f om the p epond r nc f mobile i n n the gel ph e that lectr c lly n utr l z the im mobil zed charged funct n l gr up attached to the r s n

At mod at extern l ele t olyt e ntrati ns m b l s of n cha ge alre d e s t m la ge qu ntity w th n th th t only *m nor qu a* f elect olyte a *d ff s f* m the xt rnal lutı n t atisfy Eq (3) At h gh electr lyt con c ntrat gn fi a t ele t *olyte in a ion* hould a d d es oc

Th s b ha o f e n s the b s f spec al pa ation p oces t wh h lectrol t is x l ded f m th i e ha g whil n polar *m te als* a e t F exampl h n b s parated f m gly er n by the le t pt n of tl *nonpol* gly i [J.A.M.A.]

B bl g phy F C Na hod nd J Schub *rt* (ed) I h *ng T hnol gy* 1956

Ion propulsion

I h cul m ti a sed by r a tio from the high peed d h g f a beam f ele t i lly qu lly ha g d m ute p rt l Th h rg d p ti l s r r el r ted n lect stat fi ld pro- d ced w th th h le that pr pell d Be n e g n pol ty f h rg n t b ject d f om th eh cl a e t *nded* p r d w th ut p o- du i g a b t ual ppo t pol r ty f ch g n the eh le th h c l h rg m t be m ed a part f the p op l i p oce Thu ep ate beam f po t e a d n g ti e el ctric ch rg e j ted a d mbi ed beh nd th v h l t el m ate l ct fi ld h v d the outl t The h ma f n cle r powe ed l t tat c p p l o y t m h wn i F l Th th ee ;n p l bsyst m f th pr pul system ar th pow r er t o yst m, propella t feed sy t m nd the thru t dev e Th p we gen ar sys- tem n be b ken dow i t th en gy ourc and th power-c n e s on equipment the thru t de ice into the on z r and the accel *rator*

Energy source The en rgy so rce can be a nu clear re ctor or a ol r r diation energy collector In the fir t ca e prote ti n of the electrical quip- m nt (nd of pers nnel in th ca e of manned ve- h cles) is requ r d ag i t neutr n and y rad ati n and protecti n f the ma n radiator aga n t radio- a t ity i duced in the working fluid by th reactor Effecti e neut on shielding materi ls are m tal hydrides and bo on carbide For sy tems with large electrical power outputs (megawatt range) boron carbide results in lower neutron shield weights For smaller power outputs (tens to hundreds of kilowatts) the smaller shield thickness attainable with metal hydrides contributes greater compact ness of the power package Typical *y radiation* shield materials are stainl s steel and tungsten the latter b ing ad antageous where high *radiation* i tensit es and h gh resulting operational tempera tures are in ol ed

To s mplify the pow r conver ion system it is des rable to u e the re ctor coolant as *working* fl id driving the turb ne However this is only pos- ible if the *w rk g fluid* nert such a a noble *gas l ke arg n If metal* vapor is used radi acti ity is *nduced by the reacto* lead ng to a co tamina t o of *turbi* pipel nes and radiation cooler Thi pre ding of rad oa tiv ty w uld m ke proper shield ng d ffi ult and weight onsuming Therefore two metal *ycles* as ind cated in Fig l are p ef *e able* The fi t cycle carries react r he t to a heat e ch ng r in wh ch the metal *of a second cycle* i evapo ated t d i e the turbin For th s ca e the y sh must be l cated n the far s de of the heat h ng r fo pr tect on from th *y radi* t on *of th fir t cycle metal* a well of the r act r If *only* a ingle ycle used a he t exchang n t equi d a d the y h ld ca be loc ted d ectly b h nd th n tr n shield

If the nergy so is ola *oll* ctor n ad tion sh eld i equ red d only one fl d *cycl* i r q d i a y ca e H *wever* la ge colle t r a a equ red to nt ate an adequ t amo nt f s l r e gy on the heat xchang r (see SOLAR ENGINE) Th di d antage f the sola n e gy so e a e the *requ r m nt* of c lle t r alig m nt w th the u dd ti n to flight *mechanical* thru t alignme t, the i b l ty to op r t the h dow of el *t al* body the ope ti nal t ti n t th nner s l r sy t m and the d ffi ulty f oll t r ma nt n e the pre nce f unfa abl pac en m tal co d t o s (micr meteo- rites, h gh nte ty olar rad t *n*)

Energy converter The be t d v l ped gy c n e on sy tem so fa is the t b ne generator y t m On th b s of th w k g *fluid* n d t gui hes between ga *y le a* d apo cycl *O* th b f th o ve on mechan m the tw *m t int* t g cycle the B ayt n ga turbine cycle and th Rank e y l Th B ayton cycl appe r m t d ntageo *for sm ll* pow pl nts (f a few hundred th us nd l ctr n olts)

hydrates phosphoric acid groups in nucleic acid weakly acidic phenolic —OH groups and thiol —SH groups in proteins Proteins being amphoteric behave as anion exchangers in acid systems by virtue of amine —NH_2 side groups

Since 1935 organic ion exchangers have been synthesized by incorporating functional groups in natural products such as coal lignin and peat An example of this type of organic exchanger is the product from sulfonation of soft coal The sulfonic acid —SO_3H functional groups are attached to the aromatic matrix of the coal More recently cationic and anionic groups respectively have been incorporated in cellulose fabrics by phosphorylation with urea and phosphoric acid and by reaction with 2 aminoethylsulfuric acid to provide ion exchange properties

The synthetic ion exchange resins were first prepared by the reaction of polyhydric phenols with formaldehyde the weakly acidic phenolic groups providing cation exchange properties to the product Cation exchange resins containing strongly acidic sulfonic acid groups were prepared later by the condensation of phenols and formaldehydes in the presence of sodium sulfite Anion exchange resins were prepared by the polymerization of amines with formaldehyde

The most recent technique for the production of ion exchange resins consists of first forming the polymer unit followed by incorporation of the functional ionic group For example the polymerization of styrene produces linear polystyrene chains These are held together (cross linked) by divinyl benzene to produce a network structure The sulfuric acid groups are then attached to this network by sulfonating with concentrated sulfuric acid Quaternary amines may be attached to the same matrix by an analogous treatment (chloromethylation of the copolymer followed by reaction with a tertiary amine)

These resins now by far the most popular are offered commercially with various bead sizes (mesh) and with different porosity or cross linking (percentage of divinylbenzene) The degree of cross linking controls their swelling properties The low cross linked resins swell to many times their dry volume in aqueous solution while the highly cross linked resins show little volume change In the highly cross linked resin the more rigid network structure resists the sizable osmotic pressure due to the concentrated salt solution contained in the resin gel phase As a result of such constriction ion exchange occurs more slowly because of increased resistance to the movement of hydrated counter ions in the resin gel phase Differences in resin affinities between pairs of ions are also affected—increasing with increased cross linking and thereby compensating for slowing the exchange process

High porosity in an ion exchange resin results in easier accessibility to ions of high molecular weight thereby providing a basis for their effective separation from smaller ionic species

The control of resin porosity possible in this method of manufacture permits the research worker to select the most suitable tool for his specific needs In addition these resins are chemically and physically stable and possess high capacity

The functional units most often employed in synthetic cation exchange resins are sulfonic phosphonic carboxylic and phenolic groups The sulfonic resins are strongly acidic as one would expect from their normal behavior in aqueous systems The different exchange behavior of sodium ion with a carboxylic and sulfonic acid resin illustrates this acidity function Sodium ion in a neutral solution of sodium chloride will not exchange appreciably with the hydrogen ion of a carboxylic resin in the acid form since the —CO_2H groups are not appreciably dissociated Only in an alkaline system can exchange occur readily between sodium ion and hydrogen ion The continuous removal of hydrogen ion by hydroxyl ion to form water necessitates continuous replenishment of the small amounts of hydrogen ion normally replaced by sodium ion In the case of the sulfonic acid cation exchanger the —SO_3H groups are essentially completely dissociated and exchange between sodium ion and hydrogen ion can occur normally in neutral systems

The functional groups for the synthetic anion exchange resins are usually amine When primary secondary and tertiary amine are incorporated the exchanger is weakly basic since these amines are strongly associated in aqueous systems If the functional group is a quaternary amine the exchanger behaves like a strong base

The incorporation of other functional groups to produce unusually selective ion exchange resins has been attempted with some success For example thiol —SH groups have been used to produce a resin which exhibits a special affinity for metals that form mercaptans incorporation of a chelating group *m* phenylene diglycine produces a resin with a high selectivity for the transition elements

The presence of immobilized functional groups and the neutralization of their charge by mobile ions of opposite polarity provide the resin with a preponderance of mobile ions of one charge Even in the presence of moderately concentrated electrolyte solution electrolyte diffusion (in a salt) into the resin gel phase does not alter this situation As a result there is selective transfer of the mobile counter ions under the influence of an electrical potential gradient Ion exchange membranes coherent sheets of ion exchange resin have been prepared to take advantage of this characteristic property *See* ION PERMEABLE MEMBRANE

A principal application of ion exchange membranes has been the development and improvement of electrodialysis techniques of separation For example by arranging cation and anion exchange membranes in an alternating pattern between two electrodes the imposition of a potential gradient will result in the concentration and dilution of electrolyte contained in the neighboring compar

le a d s t m Th the mal p wer tput f the ctor m t the ef b 4-16 time l rge than the kw tput. Th ne gy d fferen e m t b r d ted t pac F the g s cycle the ad at r are equ r d is at lea t 9-10 ft²/ekw at 1300 1400 F r d t r nlet temp r t whil fo mer c ry and s d m the al are 3-4 ft /ekw for 1300-1400 F 1 ft /ekw f 2000 F a d 0.8 ft /ekw f r 2300 F Depend ng n the qu r ments f r diato d n t mp t e (t l ab 1000 F t tan m 450-1000 F l m m bel w 450 F) and m c om t or pr tect n th ad at r we ght will ary greatly An al m um d n with t b du t n the wo king flu d w ll we gh a und 1.5 lb/ft the t b s be n prot ted by bumpe (ute hell) again t microm t rite p t at n Al m n m d at s fo g ycl we h 0.5-0 lb ft w th mete r bump r F te l th cor e p nd ng al ies a 1 1.5 lb ft fo tube fl id arra em ts ga y l ad t r respe t el F r y lar e ad at r of 10 000- 0 000 ft a we ght of 4-5 lb ft nclud ng l g term m r m te r p ot ct n by b mper m t be e pect d Th rad to r p e t th h a t nd l t rts mp e t f the pr p l on y t m

Alte nate p we n e s on sy tem re the m d t r a d the therm on c d od Sem o d c t (th rm ples) pr d d r ct on er n of h at t l tr ty (e THERM COUPL) P nt sy tem hs an ffic e cy f 5-6% impo ng a g eat burde on the heat rejecting radiator It i hoped w th f ture high temp rat th erm ouple to reach an efficien y f 10 13% I the th rmi nic d ode el ctron are l led ff a h t plate and are nden ed n a cold plat (see THERMOELECTRICITY) C ium a r t red between the plate t n utral ze pac charge and to adj t the work functi n f the l ctr de Th rmi nic m f m t ial for h gh t mp rat re perati n can be develop d n att in ceptable ffi nc at h gh rad ator t mperature (mall radiator area) a wn in F g 4 Be a of th cha a t ri tic and be a f the ab ence of large r tat ng eq ipment the the mi ni c n erter the mo t att ac t e co e n y tem of th future (Fig 5)

Propellant Th t ue r i n urce con ts the propellant f om it rig nal tored f rm t a s) tem of ch rged c pu le The e c n l e e ther atoms each depr d f n el ctron (p iti i n) r sm ll liqu d dr plet or l d particle t which negat e charge (le t n) s attached Th cha ged hea y pa ticle th t are llecti ly r fe red t as ll id r q re higher voltag f r the sam a ele at n o at th ame ac el rati It g y eld l e e h t l ity Pr m ng meth d of ion zati a the cesium urfa e n zat n f po l for n p op il n y tem l y E Stuh l 1954 and th n Ardenn l matr n i ce

I the urf ce on zati n sy tem e um vapor i impi g d n l t platinum r t ng ten d The i n zat n p tenti l f c ium (3.87 lt) i le s than the oltag r q i ed t rem a el ctr n f om the gr d rf e (w rk fu ct n f the plate num ti ten) Th imp ged m at m e p ate that esi m vap mp nge on the hot gr d d re por t i ngly i iz d form ha ng l t e l t n f e h i Th l l ng temper ture l m t 1130 F The d tem p at r mu t be p op ly adju ted If it i too l w n t e u h cesium e ap at s w th r ltant for m tion of a c at whi h redu s the ion zat n effi c of th g id If th temperature i to high ele t on es ap f om th s f t g ther with the io r d i g the numb r of ns ent r g th a

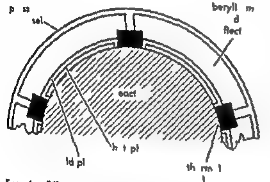


Fig 4 Effi cy f (ct) c f ct f op o l d d io l l t mp d h d l i cted l y t ms

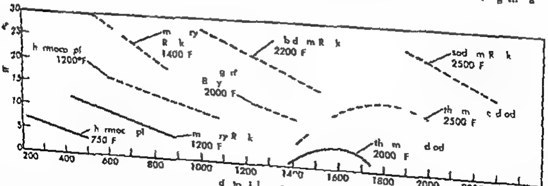


Fig 5 Th m c ert sy t m

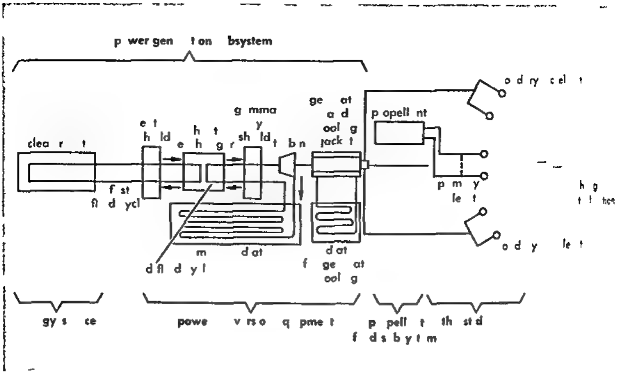


Fig 1 Schematic representation of nuclear powered electrostatic propulsion system

using a gas cycle the preferred fluid being argon a heavy inert gas A typical Brayton gas cycle system is shown in Fig 2 Heat is transferred from the reactor to high pressure gas the gas is then expanded in a turbine which drives a generator and compressor Upon leaving the turbine the gas is cooled in a radiator then recompressed and fed back into the reactor (*see* BRAYTON CYCLE) In the Rankine cycle a liquid is used for heat transfer from the reactor leading to evaporation with subsequent expansion of the vapor in the turbine the direct Rankine cycle (*see* RANKINE CYCLE) Because this would spread radioactivity the indirect Rankine cycle provides for a heat exchanger between a primary all liquid cycle and a secondary liquid vapor cycle Because of uncertainties in the boiling heat transfer rate under weightless conditions in space the intermediate link Rankine cycle of Fig 3 appears most attractive evaporation does not occur in the heat exchanger but in a boiler separator The saturated liquid from the heat exchanger is expanded to high velocity in the boiler separator A portion of the liquid evaporates In subsequent spiral ducting liquid and vapor are separated by centrifugal effect The vapor is ducted to the turbine and the liquid is returned to the heat exchanger together with liquid from the radiator in which the vapor is condensed and cooled following expansion in the turbine Suitable working fluids are mercury for smaller power plants and sodium or rubidium for larger systems

The radiator is the largest and heaviest component of the power generation system Its purpose is to radiate excess heat into space This heat is the result of limited efficiency of energy conversion The efficiency of the conversion system defined as ratio of electrical power output (ekw) to thermal

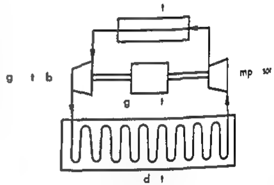


Fig 2 Power generation system using the Brayton gas cycle

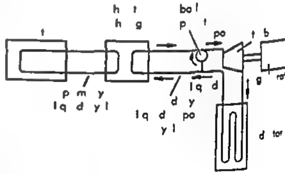


Fig 3 Power generation system using the intermediate link Rankine vapor cycle

power output (kw) of the reactor is 6-7% for 3-ekw system (mercury Rankine cycle) about 13 for systems in the 30-300 ekw range (mercury Ra kine cycle or argon Brayton cycle) and 20-23 for 1,000-20,000 kw systems using rubidium or sodium Figure 4 shows a survey of the achiev and expected conversion efficiencies of variou

cult Fort nately the field of an i n beam ext acts le tron of ne by h t fil ments the eby k ep ng h v hucle ne tral and pr ding the electro s needed for pa e-ch rge eut al zation The general arr ng me t of th lect o sou es and the o cil lating p th through the low-den it i n beam under th combin d eff ct f th ir wn th rmal elocity (wh h is compa able t the elocity f the ons 100 000–300 000 ft/ ec) and the attracting electr c field f th o beam ar shown i Fig 6

Low io mass s h gh ltage nd sh rt accelera ti n chamb rs a e requ ed for high current den ties. O the other hand for a g ven exhaust eloc ty (r specific imp l e) high thrust d n ity requ res l rg ion ma s E pec ally f r lowe spec fi im pul ns emph s on heavy i ns if a low thrust de sity i to h avo d d

The spec fi impul e c nnot s mply be elected to be a max mum but m st b optimiz d as a function of propul ion t m propul n y tem w ight, and effi ie cy of co ert ng ele tr cal powe into power of the exh ust j t. F r mi s on to the moon p c fi impul e of 3000–7000 sec are equ ed for m t Ve us or Ma s spec fic impul es of 10 000–20 000 sec a needed Spec fic imp lse be yo d 20 000 sec are f i t re t nly for mi m s to the borde s of our ol r ystem *See* ELECTROSTAC NETIC PROPULSION MAGNETOGAS DYNAMICS NU CLEAR AIRCRAFT PROPULSIO *e al o* INTERPLA E TARY PROPULSION [K.A E.]

B b iog phy R H Boden *Th Ion Rocket E gi e* Rock tdyn R pt R-645 1957 h. A Ehrick *Ion P pulsio System or O bital Stab l zat of Sat ll te E p c lly of Se l S t lli t Cl ly S mila O bits* Co air A t on t R pt ASM 2, pt 1 19 7 H S Se fert (ed) *Sp e T ch l gy* 1959 E St hlinge D g and p f rma ce d ta f sp ce h ps with n c p pul t n y tems *P d g of th E ghth I t r n l Ast a t l C g* 1958 E Stuhl g r a d R Se tz. Some pr bl ms in i n p pul n s tem *IRE T ns Mil ta y Elect es* MIL-3 (2) 27 33 1959 M A den *N w Dev l p m t Appli d l d Nu le Physic* At m En gy Rese r h Establ Tr 758 19 7

Ionic crystals

A cl f cry tal wh b th l tt e t oc p nts a l rged i n h ld t g th p ma ly by the l t tat int r t Su h b d s alled n c bi d g Fmp ll tals d i g h d by t g ab pti n f i f r d r d t on g od n c c nd ti ty at h gh t mpe a t res l th x ten of pl es l g wh h th y tal l a ily

Comp nd f t ngly l tr po ti a d t gly l t o g t e el ment typ cally form sol d wh h a y t l fo ex mple th lk l h l d tl r m l nt m tal h l des a d the lkal e rth h l de xides nd ul fid Cry t l i wh h some of th n r com pl x h a m t l a bo ates m tal tr tes d ammonium salt may al be cl sed as io ic crys tal

As a cryst l type i nic cry tals are t be dis tingui hed from ther types uch as molecu lar crystals alence crystal or metals The ideal ionic cry tal a defined i appr ached mo t clo ely by th alkali hal des Other cry t ls ften cla sed as i n c ha e bindi g wh ch is n t exclu ively i nic but includes a certa n admixture of cov lent b nd ng (see CHEMICAL BINDI G) Th s the term i nic cry tal refer to an ideal zation to which real crys tal correspond to a greater or les er degree and cry t ls e ist ha ing characteristics of more than one crystal type

Because of the relative implicity of ionic crys t ls especially the alkali halide the r thermal m chan c l opt c l and electric l properties ha e b en the subject of much experimental and theo retical n est gation

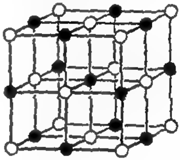


Fig 1 Sod m hl d latt ll k d t p sent p tive s (Aft F S t Th M de The ry of S l d M G w H ll 1940)

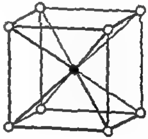


Fig 2 Ce um chl id l tt (Aft F S itz Th M d Th ry f S l d McG w H ll 1940)

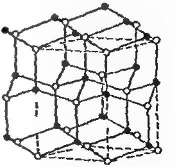


Fig 3 W rt t l tt (Aft F S tz Th Mod Th ry f S lid M G aw H ll 1940)

celerating electrostatic field. In view of the fairly high boiling temperature a high grid temperature (2200 F) is required. To avoid undue power losses by radiation over long propulsion periods a proper geometric arrangement of the grid elements is necessary. In the acceleration chamber the (positive) ions are accelerated toward the cathode (Fig. 6).

The von Ardenne plasmatron ion source uses electric discharge to produce a neutral plasma. A strong magnetic field is employed to generate high plasma density, thereby increasing the degree of ionization (Fig. 7). In the charged colloid system the fine droplets or dust particles must be produced first, then must be ionized. The various possibilities of producing colloids and accomplishing their ionization efficiently are not yet fully explored. See AEROSOL; COLLOID; see also SMOKE.

The space charge represents one of the major obstacles of any ion-propulsion system. By expelling a singly charged beam, repulsive forces tend to diverge the beam. Therefore high current density calls for fast beam acceleration, high voltage, in a short accelerator. The Rocketdyne Division of North American Aviation has reported current densities of ~20 ma/cm² with cesium, 6000-volt acceleration and an accelerator length varying from 3 mm to a fraction of 1 mm. Although space charge limits ion beams to a density in the order of $10^{?}$–10^{11} ions/mm³, space charge effects require rapid neutralization of the beam after it has left the propulsion system. Continuous ejection of one charge would gradually charge the ship in the opposite direction and high speed ejection of the ions in ...

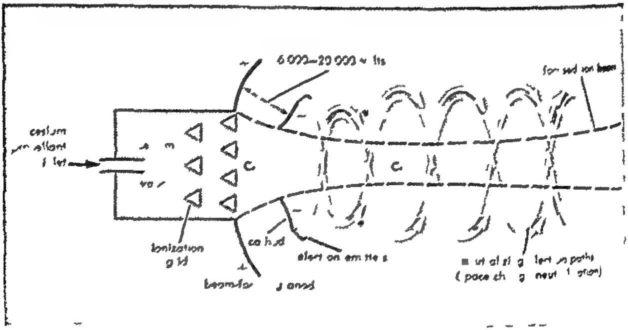


Fig. 6 Cesium ion thrust device

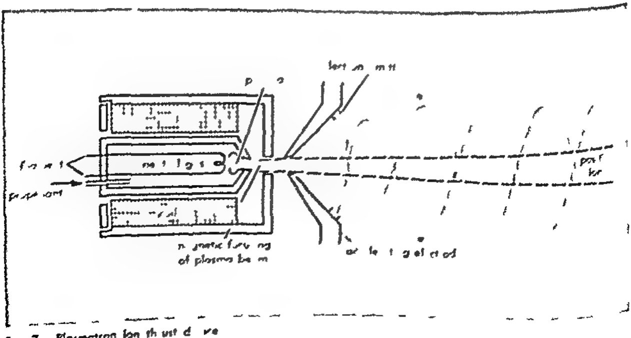


Fig. 7 Plasmatron ion thrust device

cult F rtu ately th field f an ion beam tracts lectrons f n arby h t filaments thereby keeping th eh cl neutral and pro d ng the electron needed for pa e-cha ge n ut alizati n The g neral arr gement f th el ctron s u c a d tl iro il l t ng p th through the low den ty on beam under the mb ed effect of the r own thermal v l ity (wh h is mparabl t the el c ty of the ion 100 000–300 000 ft/ ec) nd the attr ct ng electric field of the i n be m are hown in Fig 6

Low i n mas es high voltag and hort ccelera ti n chamb are required for high current den i ties On the other h nd fo g en exhaust elocity (or specifi mpuls) h gh thru t density requires la ge i n m s Especially for low r specific im pulses emph si is n heavy i ns if a l w thrust d ity is to be a ided

Th specific mpul e cannot mply be el cted t e a maximum but mu t b opt mi ed a a fun tion f p opulsion t me, pr pul on sy tem we ght and ffi ie cy of on eru g el ctri al p we into p wer f th exhaust jet. For mis ns to the moo spe- cific mp l s of 3000–7000 are requi ed f r n ions t Ven s Mars, specific impulses f 10 000–20 000 ec r needed Sp c fic impuls s be- r d 0 000 sec a e of nte e t nly f r m s i ns t th borders of our s lar sy tem *See* ELECTROMAG- ETIC PROPULSION MAGNETOGAS DYNAMICS NU CLEAR AIRCRAFT PROPULSIO s l o INTERPLA E T PROPULSION [K A E]

B bl gr phy R H Bod n *The Io Rocket F gi e* R cketdyne Rept. R-645 1957 K A Ehricke *I P op l Sy t m O b tal S ab li t of S tell t s F p c ally of Ses l Sa ll t Cl s ly S mil O bits* Con ai Ast naut c R pt. ASM 2 pt 1 1957 H S Seifert (ed) *Sp T hnology* 1959 E Stuhl ng De n and p rf rman dat f spa sh p with ic p pul ystem *P c d g f the E ghth I t na ti l A t t c l C ng s* 19 8 E Stuhling r nd R Se tz. Some p oblem i n p p l y t ms *IRE T ns Milit y El ct o cs* MIL-3 ( ) 2 33 1959 M A d ne N *w Dev lop m t n Appl d Io d N l a Physic* At m c E e gy Res h E t bl Tr s 758 1957

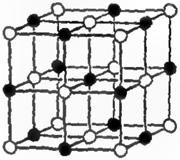
Ionic crystals

A l s f y tals in wh l the l tt e t o u p l a h g d held t g ther p m ly by th el t t l nte ti Such b nd g lled n b nd Emp ll ry t l a d t gu h d by ng ab pt f nf a d d t good i d t ty t h gh t mp r t es d th i te e f pl alz g wh h th y tal l e ly

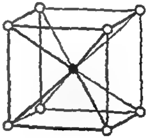
Compo d f i o gl l t op t v a d i o gly elect n gat elem t typi ally f rm sol d h h a e c y t l f ex mpl th alkal h l d th m o l nt met l h l de a d th alk l e rth h l d x des nd ul fid Cry t l i wh h some f th ar m pl h m t l bo at m tal n t t d ammon um alts may al o be cla d as i nic cry t l

As a crystal type i ni crystals are to be dis- tinguished from other types ch as m lecular crystal lene cry tal or metals The ideal ion c crystal a defined i appr ached m t clo ely by th alk l hal des Other cry tal often cla ed as ionic ha e bind ng wh ch i n t exclu i ely i n c but includes a certain adm xture of co alent bind ing (s e CHEMICAL BI DING) Thus the term ionic cry tal refers to an idealizat on to which real crys- tals corr pond t a greater or les er degree and ry tals exi t having characteri tics of more than o e crystal type

Becau e of the relati e simplic ty of ionic crys- t l espec ally the alkali hal des their thermal mechan al optical and electrical pr perties ha e be n the subject f much experimental and theo- retical in e t g tion



Fg 1 Sod m hl d l tt Bl ck dots r p e t po tiv (Aft F S t Th M d Th y f S l d M G w H ll 1940)



Fg 2 C m hl d l tt (Aft F Se t Th M d Th ry f Sol d M G w H ll 1940)

Fg 3 W rt t l n (Aft F S itz Th M d Th ry f S l d McG w-H ll 1940)

celerating electrostatic field In view of the fairly high boiling temperature a high grid temperature (2200 F) is required To avoid undue power los es by radiation over long propul ion periods a proper geometric arrangement of the grid elements is nec e sary In the acceleration chamber the (positive) ions are accelerated toward the cathode (Fig 6)

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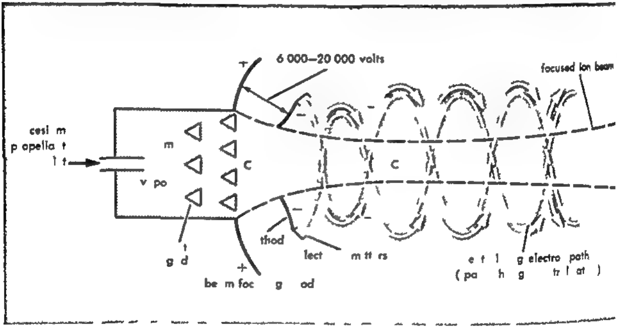
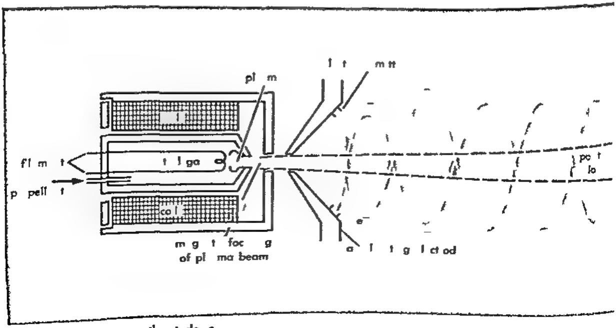
The space charge represents one of the sev obstacles of any ion propulsion sy tem By prod ing a singly charged beam repulsive Coulom forces tend to diverge the beam Therefore, hig current density calls for fast beam accelera ion b high voltage in a short accelerator The Rock dyne Division of North American Aviation has re ported current densities of 3-20 ma/mm wi cesium 6000-volt acceleration and an accelera length varying from 3 mm to a fraction of 1 m Although space charge limits ion beams to a de sity in the order of 10^{9}–10^{x} ions/mm spa charge effects require rapid neutralization of t beam after it has left the propul ion system. Co tinuous ejection of one charge would grad al charge the vehicle in the opposite direction, mak high speed ejection of the ions increa ingly d



Fg 6 C um o thrust de e



Fg 7 Pla mat on i n thr t de c

he f ll w g nume ati n f th tep n the Born Hab r y l (A) nd ate l me t A ı a mo ı m g eou t te d [A] indic t s A ın lid tate d The B with t br k t ı step (3) r fer to th n tu al f rm of B at th g en mp ature nd p essu e The ıo ı mp u d ı ken t b AB wh A ı the el t opo tı e d B the el tr neg t e elem nt

Th tep f th B rn Habe Cycle (ll tempe a tures n K and p s res n tmo ph re)

1 $[AB]^{0}_{P} \rightarrow [AB]^{0}_{P=1}$ The al f ΔH_1 ın th s th rm l mp n ı ry mall and can be n l ct d mp r n w th oth r he t c nt nt ha es ın the ycl

2 $[AB]^{0}_{P=} \rightarrow [AB]^{298}_{P=1}$ In tl step the crystal ı rmed t oom temper t r The al e of ΔH can be l l ted f m th spe ıfic h at t c nstant p es f th rystal

3 $[AB]^{0} \rightarrow (A)^{298}_{P=1} + B^{298}_{P=1}$ The v l e of ΔH gı n by th h t f f m t n of the c m po d AB h ch ef r ed to s bst nces n the n t r l f rm t tand d temper tu e and p essu Se THERMOCHEMI TRY

4 $B^{298}_{P=1} \rightarrow (B)^{298}_{P}$ The l e f ΔH the d t n n rgy c s y to f rm m n tom c gas f m B t l stat t standard tempe t nd p ess re F chlo des f e ampl th s s th d s at n n gy f Cl_2 mol ul to Cl t m

5 $[A]^{298}_{1} \rightarrow (A)^{298}_{P}$ I th s t p ΔH_5 s the h t f bl m t n of th metal A It n be ded ced f m th he t ff ı the pe fic h t f th s l d, l q d nd gas phas s nd th po p es d ta f r th m tal See SUBLIMATIO

6 $(A)^{298}_{P} \rightarrow (A)^{0}_{P}$ $(B)^{298} \rightarrow (B)^{0}_{P=}$ An d abatıc pan n f th ga ns d ed as deal t ry l g l m res Its n a stat wh h $P = 0$ $T = 0$ and $\Delta H = -\frac{5}{2}RT$/m le wh R th g tant

$(A)^{0}_{P} \rightarrow (A\ )^{0}_{P} + ^{-}$ The nızatı n of the A at m g s ΔH pe t m ta l t their first zat y

8 $(B)^{0} + \ \rightarrow (B^{-})^{0}$ Th l ctr ns fr m tep (7) a pl ced the B toms Th alu of ΔH pe at m n by the el t n affin ty f th t m (see ELECTRO EC TIVITY)

As ample fo sod um hlo d $\Delta H \cong 10^{-4}$ (k local rıes/m l) $\Delta H = 2.4$ $\Delta H = 98.3$ $\Delta H = 60$ $\Delta H = 88$ $\Delta H = -29$ $\Delta H = 119$ and $\Delta H = -80.5$ Experım tal c hes rgies for n mbe f the n ry t l ar gı n ı the mpa g tabl See CHEM CAL STRUCTURES

B May q t By e f the B rn Made l g mod l the c h e f a ı n c ery ı l n be l ted ı ı m ed mp ıb lıty a d

Cohesive en rgies

Cry t l	Stru t re	U_{exp} kcal/mol	U_{calc} kcal/m l	U_{cal} fi ed kcal/m l
L Cl	N Cl	01	196 3	00
LıB	N Cl	191 5	181 4	189 5
LıI	N Cl	180 0	169 1	1 6 1
N Cl	N Cl	181 7	18 0	183 5
N B	N Cl	1 5 9	1	1 5 5
N I	N Cl	166 3	159 3	161 3
KCl	N Cl	16 8	165	167 9
KB	N Cl	161	158 3	161 3
KI	N Cl	15 8	148	15 4
RbCl	N Cl	163 6	1 9 1	16 0
RbB	N Cl	159 0	1 1 9	156 1
RbI	N Cl	149 7	143 1	148 0
C F	Fl orıt	618 0	617 7	
C Cl	Z bl d	6 3	06 1	
Z S	W tz t	8 1	816	
PbO	R tıl	831	6 0	
AgCl	N Cl	07 3	187 3	

Th cohes gıes th l t tw col m re cal cul ted us g th Bo M y eq t d th ref ed Bo M y theo y espect ly Th f d l l t f th l t fi y tals med h t bee m d

lattıc pa g B ca e of the opposite signs of elect c h rg which they carry the unl k ı n ı s ch a cry t l m del att act one an ther acc rd ı g to Co lomb s law Howe er ch a charge d t b tıo nn t be n qu librium ıf ly Cou l mb f ce ct I addıt o t th ır Coul mb nt ra tı the ı exh bit a repul on wh ch ompa ed w th the Coulomb ınter t arıes ap dly w th ınte ıo ı epa at n The repuls on be m st ng f r small separations and dımı he r ı dıy fo ı rea ng eparat on The st t c qul br m c nfigu atı n of the cry tal d ter m ned by a bal n e f these f rc of ttr tıon nd p l o

Th h rt a ge rep l on betw n ns m t be des bed by q a t m mech nıc Wh n the el t n b t f two n lap the l ctr harge de ty th g n f erlap ı dım nısh ed a a c seq ce of the P ulı e clu on p ın ple Th ch rg ed t b t n re It ın pul ı between th ı n ın add t t th Coul mb ınte t on which they ha e at all ter onı dı t nce I a ly wo k th e gy V due to pul o of two s t a dı t e r w ssum d t ha e th f m

$$V_{re} = B/$$

whe e B nd n a e tants to be d te m d Qu t m m h l l latıo s f th ınte ac t o of at m w th l ed shell f l t nd ate that th t ctı n f r pulsı n s bette pp m t d by an exp ne t l dep dence nt c d t

$$V_{re} \quad A \quad /$$

wh A a d p a c st nts B th f rm f l g almo t the am l l ted he ı e en gy th p tı l f m g s sl ghtly b tt m t with p m t

Crystal structure The simplest ionic crystal structures are those of the alkali halides At standard temperature and pressure the 16 salts of Li Na K and Rb with F Cl Br and I have the sodium chloride structure of interpenetrating face centered cubic lattices (Fig 1) CsF also has this structure but otherwise the cesium halides have the cesium chloride structure of interpenetrating simple cubic lattices (Fig 2) The sodium chloride structure is also assumed by the alkaline earth oxides sulfides and selenides other than those of Be and by AgF AgCl and AgBr Other crystal structures such as the wurtzite structure (Fig 3) assumed by BeO β ZnS and ZnO and the zinc blende structure (Fig 4) assumed by CuCl CuBr CuI BeS and α ZnS are also typical of the ionic crystals of salts in which the atoms have equal positive and negative valence Ionic compounds consisting of monovalent with divalent elements crystallize typically in the fluorite structure (Fig 5) assumed by CaF_2 BaF_2 CdF_2 Li_2O Li_2S Na_2S Cu_2S and Cu_2Se or the rutile structure (Fig 6) assumed by TiO_2 ZnF_2 and MgF_2 *See* CRYSTAL STRUCTURE

Cohesive energy It is possible to understand many of the properties of ionic crystals on the basis of a simple model originally proposed by M Born and E Madelung In the simplest form of this model the lattice sites are occupied by spherically symmetric ions having charges corresponding to their normal chemical valence These ions overlap only slightly the ions at neighboring

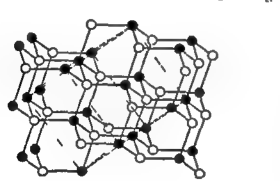
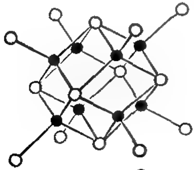


Fig 4 Zinc blende lattice (After F Seitz The Modern Theory of Solids McGraw Hill 1940)



● F ○ Ca

Fig 5 Calcium fluoride lattice (After F Seitz The Modern Theory of Solids McGraw Hill 1940)

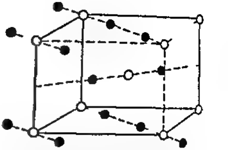


Fig 6 Rutile lattice (After F Seitz The Modern Theory of Solids McGraw Hill 1940)

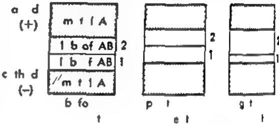


Fig 7 Experimental arrangement for ... conductivity

sites and interact with one another through central forces In NaCl for example the spherically symmetric closed shell configuration which the free Na and Cl ions possess are considered to be negligibly altered by the crystalline environment and to have charges $+e$ and $-e$ respectively where $-e$ is the charge on the electron Using this model together with certain assumptions about the forces between the ions Born and M Goppert Mayer calculated the cohesive energy of a number of ionic crystals This cohesive energy is defined as the energy necessary to take an ionic crystal from an initial state in which the crystal is at 0 K and zero pressure to a final state which is an infinitely dilute gas of its constituent ions at 0 K and zero pressure *See* COHESION (PHYSICS) While it cannot be measured directly this cohesive energy can be deduced from experimental quantities by the use of the Born Haber cycle Thus the validity of the simple model of Born and Madelung can be tested by comparing the calculated cohesive energy of Born and Mayer with the experimentally determined values

Born Haber cycle This is a sequence of processes leading from the initial to the final state specified in the definition of the cohesive energy Because in most of the processes in this cycle heat changes at constant pressure are measured it is convenient to consider the change in heat content or enthalpy $H = U + PV$ where P is the pressure V is the volume and U is the cohesive energy rather than the change in E in each step Since the total change in H is independent of the intermediate steps taken to accomplish it the ΔH for the change in state specified in the definition of cohesive energy will be given by the sum of the ΔH in the steps of the cycle Furthermore because when $P = 0$ $\Delta H = \Delta U$ the ΔH thus calculated will be the cohesive energy In

r of elect oly rel t ng the charge t an p rt d th matt tran port i hown t b ald If c r nt w re c d by free elect n this uld not be the c s

In mber of i n c cry tal t ha b n e tab- h d wh h { the on a e re pons ble f r th nd cti a d h w they move In a c y tal f th pe \ B an e perim t t determ ne the r l t v intribut of A and B i s t the io i c n u n ty i d ne i the foll wi g ma ner { e 'g 7)

Two lab 3 nd 2 of the cry t l A B ar e ed tog th r b tw en ele t de of m tal A d a current i pa d th ugh them. If the posi o al ca r ed th rre t th c thode ro ld n r a n we ght ■ d the anod w uld de- a but th lab w ld ema n uncha ged i

If on if othe f nd n gat i ns al ne a r d the cu nt the e i ns would b omb ned r th th m tal f th n de to n e e the th ck es f lab 1 wh le em l f negati i n f om ih g on f th ath de ould c u e t to in r a t we ght th po t on of the bo nd y b tw en 1 nd t mo i ■ In g neral the ca w ll be n t m d te b tw e th ■ extr mes By weigh ng the l ct d nd the slab b f e a d ft r p s- ing cur t can n pr pl d t rm n the fr c ti n f th ent arr d by th po it e nd n g t on These fr i n wh ch a e lled the tra sp rt umber f the on d ffer for d ffe e t cry t ls

[i o d t ty eq i th moti n f i n the latt and th i ncern d with d part re f m the d l ry tal de c ib d thus l r l the m l eq l b m at temp r t es bo e 0 K the e lway po t nd gati i n a an e nd nt r t t l i n p e e t A ac cy form d by re- m g a latt ce- ite c pa t t th u fa e f th ry t l l a g b h nd a v a cy ll d a Sch ttky def t If the a n v f m d by em ■ n i to n i t tt l p t n fa f m th a y th a y nte t i l p s call d F k l defe t The mb r f e h l th e d fect ■ nt d pe d on the tempe t re the f rm t gy f th d f t th ■ mb r f t ti l tes a d c n de t s f l etre c l neut li R th th d t iate h ng f on th d l cry t l t the m t n f the a an a d tf t t ti l i ns r both that s pon bl f ■ ondu ti t The mech n sm esp s ble f r i n o du ti ty al t pon bl f elf-d ffu { s th ry t l nd t d f th tw pl nomena ha h lp d t la f th mecha ms I ■ migrat n { Dir r si r t i ns) E pe me ts h sho n that i lkal h l d S h ttky defe ts p ed mi t nd th t ■ c nd ti ity or u h fly th o gh p si t n y m g ati n f the l h l le on tl th h d F kel defe t pred m n t nd pr t i n ter t t l m gr t n by th nt t t l y m h n m th m t ign fic t p e s l ed

Ionic c nductivity is only one of many p r pertie of ionic crystals which depend critically on the d f cts in the cry tal Se CRYSTAL DEFECTS

Dielectric properties The p larization of an on c cry tal in an pplied time arying electric fi ld depends n the f equency of the fi ld If = 0 the fi ld i t t c and a stat c equ librium will be achieved in wh ch th i ns are d place l fr m the r latt ce ite d tance determin d l y a balance betwe n the f rce of repul on d e t their ne e t n ighb rs a d the electrical f rc on th i ns Opp t ly cha g d ions move in pp ite d ect o s with a re ult n ion c p larization In addit n th el ctr n cloud of th ion are de f med i the local electri field at th ions a d to a much le r ext nt by the repul i e forces t gi e an le t oni polar zation As the frequency ■ increas ine tial ffects m t l co d red When s ffici ntly h gh that i when $v >$ { i the n tu al f equ nc of v br tion of ion about lattice te) th he v i n ca no l nger f llow the r p d v riat ons f the appl ed field The o ic p larization cea e to c nt ibute to the t tal pol ri zat on although th le s mas ve ele tr n cl ud co tinu t gi n lect on c pola zat n Eve tu lly with inc ea ing fr q ency ex eeds th f eq ency at h ch the ele tr n cl ud d formation can follow th field and the el tr nic p la i zat n be me altered The freq ency i, called the restrahlu g ■ ■ du l y f eq iency lies in the nf r d eg ■ nd the iat d br ti n of the charged o s a e e pon ible fo th st ng b pt o of nf a ed r diat on in i ni cry tals The term re d al ay f eq en y c mes fr m the fa t th t th reflect ity of is ble and inf ared ad ation is h h t f r rad at on f frequen y ea to th t of max mum al o pt n Thu mult ple efl ti n w ll y ld r di t on c mp sed p ed mi antl of e d al ys of f equen y ne to For add ti nal inform t on o re dual rays s e RE LECTIO (ELECTROMAGNETIC RADIATION)

Ionic radii It h s been f nd that n radi a be h se ch that th latt c pac ng of o ic ry t ls r gi en appr imat ly by the s m of th r d i of th on t t nt ion Thus f n t nc 8 rad i s ffi e t g e th app ox m t latt c p c i g f the 16 all li h l d s ha i g sod um chl de t ctu Th s is tru b u e of the p d aria t on of th repul ive nt ct n with d tan e so th t the i s i t ra t som what l ke l d ph es Th e i the impl at n that a g en ha g th me i nic radiu in a a iety of ry tal ha n lect n clo d wh h s only sl ghtly ft d by the d ff ng ry tall n om t l th rys- tals S ral tabl s of io adi appea in th r f ere ces gi en i the bibl ogr phy [B C D]

Bibliography M B rn and K. H ang *Dy n m l Theo y f C yst l Lattic* 1954 C. K t *t l I t d ct n to S l d Sta Phy cs* 2d ed 19 6 L. C. Paul g *Th N tu e f the Chem al Bond* 1939 F Se tz *Th M d n Th y of Sol d* 1940

Using the exponential form for the repulsive interaction energy the potential energy $\varphi(r_{ij})$ of a pair of ions i and j can be written

$$\varphi(r_{ij}) = \frac{Z_i Z_j e^2}{r_{ij}} + Ae^{-r_{ij}/\rho}$$

where $Z_i e$ and $Z_j e$ are the net charges of the ions i and j and r_{ij} is the distance of separation of their centers The assumption that the ions are spherically symmetric has been used here in writing the Coulomb interaction as that of point charges

The cohesive energy U of an ionic crystal due to the Coulomb and repulsive interaction of its ions is the sum taken over all pairs of ions in the crystal

$$U = \frac{1}{2} \sum_{ij}{}' \varphi(r_{ij})$$

where in the summation the lattice site indices i and j range over all sites of the crystal The prime on the summation sign indicates the exclusion from the sum of terms for which $i = j$ and the factor of ½ avoids counting pairs of ions twice

For crystals in which there are only two types of ion the Coulomb or electrostatic part of U U_c can be written in a simple form

$$U_c = \frac{1}{2} \sum_{ij}{}' \frac{Z_i Z_j e^2}{r_{ij}} = -\frac{N\alpha_M (Z_+ Z_-) e^2}{r}$$

where $+Z_+ e$ and $-Z_- e$ are the charges of the positive and negative ions N is the number of ion pairs in the crystal r is the nearest anion cation separation and α_M is the Madelung constant *See* MADELUNG CONSTANT

By anticipating that ρ will be small compared to the nearest neighbor separation the interactions of repulsion may be neglected for pairs of ions other than nearest neighbors The energy of the crystal model for arbitrary nearest neighbor separation r is then

$$U(r) = N[-\alpha_M Z_+ Z_- e^2/r + MAe^{-r/\rho}]$$

where M is the number of nearest neighbors which each ion has in the crystal

The parameter ρ may be evaluated for a given crystal by requiring that (1) U be a minimum for the observed value of r and (2) that the compressibility of the model equal the measured compressibility of the crystal It follows from these requirements that

$$U(r_0) = N\alpha_M Z_+ Z_- (1 - \rho/r_0) e^2/r_0$$

This is the Born Mayer equation for the cohesive energy where r_0 refers to the nearest neighbor distance at static equilibrium Further in this equation ρ is given in terms of experimental quantities by

$$\frac{r_0}{\rho} = \frac{18 r_0^4}{\alpha_M e^2 K} + 2$$

where K is the measured compressibility of the crystal

Cohesive energies for some alkali halides and crystals of other structures calculated in this way are shown in the accompanying table where they can be compared with the experimental values for the cohesive energy The agreement is considered to be support for the essential validity of the Born Madelung model The model has been applied with some success even to the ammonium halides assuming spherically symmetric ions

The Born Mayer theory has been refined with resulting improvement in the agreement between the calculated and experimental cohesive energies for alkali halides The refinements have considered the small (a few kilocalories per mole or less) corrections to the cohesive energy arising from Van der Waals interactions and zero-point vibrational energy The Van der Waals forces are weak attractive forces between ions due to mutually induced fluctuating dipoles Similar forces even weaker due to dipole quadrupole interactions have also been considered Both these interactions make small positive contributions to the cohesive energy At 0 K the lattice is not in static equilibrium but as a consequence of quantum mechanics is in a state of zero point vibration with nonzero energy The energy of these vibrational modes can not be further reduced The zero-point vibration energy gives a small negative contribution to the cohesive energy The results of these refinements are also shown in the table *See* LATTICE VIBRATIONS

While it has had success in calculating the cohesive energy the shortcomings of this simple model become evident in its failure to predict correctly the elastic shear constants of ionic crystal This requires interionic forces of a noncentral character which are absent from the model There are also other instances in which the simple model is found to be inadequate

Ionic conductivity Just below their melting point ionic crystals have conductivities of the order of 10 (ohm cm) Below the melting point the conductivity falls rapidly with decreasing temperature In a temperature range sufficiently near the melting point the temperature dependence of the conductivity σ is exponential and of the form $\sigma = ce^{-\phi/T}$ where c and ϕ are constants In this so-called intrinsic range the conductivity is characteristic of the material and relatively unaffected by small concentrations of impurities and the previous thermal history of the crystal At lower temperatures σ departs from the exponential behavior of the intrinsic region in a manner which does depend on impurities and history For positive divalent impurities in alkali halides these departures have been extensively studied

Ionic conductivity involves the transport of ions as shown in experiments in which the deposit of metal from the ionic compound on the cathode is measured after the passing of current Faraday's

n t be fl t plates but ar m t m cyl ndr cal or phe c l A mmonly sed t izatt chambe h s sphe al m tal uts d h ll nd a maller m t l phe in d B w en the tw sh lls an el t pote tial s maintain d nd the ionizati c rre t m ured

If izat chamber t b u ed t detect the nizatio p duced by a ngl p rticl th c rr t m as ri g de e mu t b extrem ly nsi t e n the rrent pr du d e y sm ll A ingl α-partic l of 3 Mev e gy wo ld p oduc bout 10^5 po iti e r $1.6 \times 10^{-}$ oul mb f cha g An mplifi mu t be u ed to in ea th iz f the c rrent pulse so that t c n be m as ed o d play d on n osc ll cop Th e re t t the i zati chambe s pa ed thr ugh l igh ta (Fig) d the ltage gene at d by th c rr t the s stan ampl fied t a h s ampl fie

The p l e f urre t ed by the ep at on f ha g in the hamb take a mpli t d form wh h d p d n th typ l g s n the cl mb I a r the el ctrons th t are knock d ff the m lec le rap dly att h t mole ules of ygen, p od ing neg t xyg n i ns At m c m lec lar o m v al wly i the lectr field beca e f the l g ma s ompa ed to elect n I pu e m n tom ga uch g the l t n do n t att h t the t m a d th s the n g t e h ge m m h mo e p dly th n th p t ha g So-c ll d f t to hamb th e m d t t ke dva t ge f th ap d m t n f lect o If lect coll t n s ed th m pl fie mu t l o b m de t re p nd t th r p d ollect n f le t The collect time f electr g s chamb ab t l μ S h h mb m y b ed f n ng r tes up t 10^5 t / ec If th h e i ns a e u ed t ad f le t o s th oll t o t me bo t l msec nd nt g ates p t 10 p r ec b obt ed

Proportional counters A l ger p l ob t ed f th olt ge a th zat h mb is ed and th ele tr s cele ted s ffi tly t g ne at dd t l l t U d h d t th dev ce t u lly called a p o po t l t r n th m red p l e ze p port l t th g l n zat n n the g P port al nt s lly m d w th cyl d l lect de w th a fi w tl ent l od La g n zat ch mb s 6 ft l ng a d ft d h bee ed n c m y p iment f zat hambe l nd w th the ame d m te h e bee ed t eut t l r t B a ppe al m um ed f th lect ode a d gla pla t mbe f th l t

Fission chambers N tr s b d tect d a p ll l pl t n zat n ch mbe whi h fi ll m t l h bee ated the pl t Wh n n t n t the u leu f a fi ble t m th n l d t g tes p od g ev l f g ments whi h can au e i nizatio in the gas Not all the eutro e tert g such a chamber will make a ou t Som of th m will pa s through the cl am ber with ut ent ng a nucl s of th fi onal le mat rial Othe s may p duce fi on but th fis si n f agm nts bei g f limited range may re mai in th lid mate al F n ch mb s al way ha h gh backgr und or α part cle co nts becau the fis o able material is radi cti e

[w n r]

Bibl og aphy II B II t a d H H Staub *I ni zati Chambe d C nters* 1949

Ionization gage

An i trume t for mea uring acuum by onizing ga a d measu ng the current *See* VACUUM MEASUREMENT I izat gages may be cla ified l y th me used t the

In the h t filament i zati n gage el ctro s em tted by an i a d cent filame t attracted t w d a positi ely ch rg d gr d electr de Col l s f ele t ns w th gas m lecules produ e n The ions are attracted t neg t ely charged elect od Th n c rr t i a m re f the n mber f m le ules f ga hence of the acu m (p e sur)

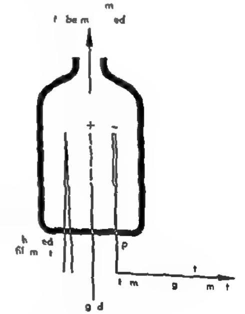


Fig 1 Hot fil me t t g g

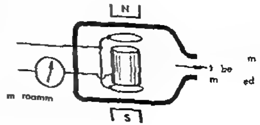


Fig 2 C ld-c th d (Phil p) t g g

Ionization

The process by which an electron is removed from an atom, molecule, or ion. This process is of basic importance to electrical conduction in gases and liquids. In the simplest case, ionization may be thought of as a transition between an initial state consisting of a neutral atom and a final state consisting of a positive ion and a free electron. In more complicated cases, a molecule may be converted to a heavy positive ion and a heavy negative ion which are separated.

Ionization may be accomplished by various means. For example, a free electron may collide with a bound atomic electron. If sufficient energy can be exchanged, the atomic electron may be liberated and both electrons separated from the residual positive ion. The incident particle could as well be a positive ion. In this case the reaction may be considerably more complicated, but may again result in a free electron. Another case of considerable importance is the photoelectric effect. Here a photon interacts with a bound electron. If the photon has sufficient energy, the electron may be removed from the atom. The photon is annihilated in the process. Other methods of ionization include thermal processes, chemical reactions, collisions of the second kind, and collisions with neutral molecules or atoms. *See* ELECTRICAL CONDUCTION IN GASES; ELECTRODE POTENTIAL. [G.H.M.I.]

Ionization chamber

An instrument used to determine the ionization produced by fast-moving charged particles. Ionization chambers are a type of particle detector and may be used in cosmic-ray research, in nuclear physics, or as radiation survey instruments which indicate the level of intensity of radiation at a point. *See* PARTICLE DETECTOR.

When a charged particle moves through a gas, it may pass near enough to an atom in the gas to remove an electron from the atom by the process of electrical attraction or repulsion. This is called ionization of the gas atom. Left behind are the negatively charged electron and the atom, the latter with a net positive charge. The function of the ionization chamber is to measure the total amount of charge separated in this way by the passage of the charged particle.

Ionization chambers are constructed with two electrodes across which an electrical potential is placed. The negative charge produced in the gas moves toward the positive electrode, and the positively charged ions move toward the negative electrode. The current of moving charges is measured to give the total ionization produced in the gas.

General types. Ionization chambers are of two general types: those used to detect radiations from radioactive substances placed directly in the chamber, and those used for detection of higher-energy particles originating outside the chamber, such as those from a particle accelerator. In the first category, α-particles from naturally radioactive substances are usually detected by placing the substance in a parallel-plate chamber directly on one of the plates. The pressure of the gas is adjusted so that the α-particles are stopped before they reach the opposite plate. Such a counter gives information on the half-life of the material or on the amount of active material present if the half-life is known. An ionization chamber used to detect β-rays (electrons) from radioactive substances must be much more sensitive than an α-particle counter because the specific ionization produced is much smaller. Usually either a proportional counter or Geiger-Muller counter is used to detect β-rays (*see* GEIGER-MULLER COUNTER). Ionization chambers have been used, however, to detect electrons and other singly charged fast-moving particles from particle accelerators or cosmic rays. In this application the gas must be carefully purified and the amplifiers must be of high gain and well stabilized.

Electroscopes. The simplest ionization chamber is the gold-leaf electroscope, in which measurement of the angular deflection of two gold leaves in a gas-filled container indicates the ionization produced in the gas (*see* ELECTROSCOPE). Ionization chambers based on this general idea are widely used as indicators of charged-particle radiation. They are made in small sizes for convenience (they are often shaped like a fountain pen) and are carried by people who work near sources of radiation. *See* MONITORING (IONIZING RADIATION).

Current measurement. For accurate measurements of ionization, it is necessary to measure the actual current produced. A pair of metal plates mounted in a chamber that contains the gas in which the ionization is produced is connected to a battery and current-measuring meter, as shown in Fig. 1. The ions produced in the gas are separated by the electric field, and the current of ions is measured by the meter. The metal electrodes need

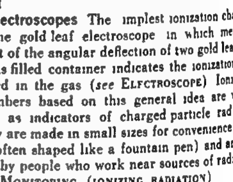


Fig. 1. Ionization chamber circuit.

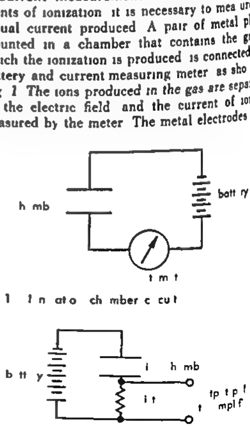


Fig. 2. Pulse ionization chamber circuit.

refl ctı n fr m th ıon phere The f ct that w ld wıd radı mmun at e tr ct d to fre qu l s than abo t 30 m gacycles pe ec nd s a ocı ted with the fa t that eflect on of radio wa e fr m the n pl re s n t bt ıned at h gher r d f eq en ıes

Refinements of investigation The h ghest r d o f q ency at whı h t ı p ıbl to bt ı r da reflect n fr m the ı no pher ı a m a r of th m x mum l t on d n ty ın the ı o phe e Dur ng the p st quarter f c ntury n tw k f n sph r c b rvato es ha b n e tabl hed ve th w rld with th bj ct of me ıng the maxı m m l tr n d n ıty ın the ı no phe and ert ı the ınt estı g n sph r pa am ters, s func t n f th t m f day th sea on of the ye r the latt de a d th degr e f la a tı ıty It h s b en f und that the degr of onı atı n ı the ı n sphe s l ly d p nde t pon the z n th a gl l the su The ele t de ıty ıs h gh when the s s ne r th z n th and g d lly d appears aft u t. P rt c larly at the highe level ın th o phe the ele t n dens ty d ppe r at n ght l wly eno gh that m o at o always ex sts n the on sphe e E at the poles d n g the pe od f p p tu l d kn me zat n ısts ın the n sph e The l s la ntrol of the ı o ph e ı nfirm d by ob erv ıo s mad durı g umer us l r l ps A maj r f ctor ı th ı at of the ı o ph the bso pt f ultra let l ght f om th If th ult av ol t l ght fr m th u we e ot almo t omp] t ly ab bed the n ph re l f at the su fa of the rıl w ld t ad lly mod fıed

Alth gh th m latı n of k wl dge con er ng the ı n pher s ı 1925 h bee larg ly h e d by d om th d the m a s ar a a l l l fo t dyı g the ph Th lu ı o ph me n kn w a th ur r o t o o ph rı lev l nd almo t e rt ı ly as oc ated w th x ıtatı n d on zat on f tm sph rıc at m a d m l les by n m n p rticles as oc ted with la a t ty In th ab n e of the moo d l a t f al l ght, the ll m natı n t the ground ı du ed m n tly t d atı f m x ı d at m m l c le the tm ph re at phe ı lev l Th l m n t al p od d by d nt grat f n m g met r al o oc u t ph le el ll t dyı g ll f th e phe m po bl to m k m r ded t g th ph e l t t f th n ph e M teo m ecent s a t ha become f s bl t d ı me t d ectly nt th o ph w th th d f ock t a d tell t s Th n d bredly pen w f ph t estıg t d ad lly h ges th mp rtan e f the n ph a p t (m n n ı nm t

Gaseous character and frontiers In th no ph th tm ph re t e t em ly te uo E n t th l w n ph r lev l th number f m lec les pe t l m bo t 10 000 t m les th n t th u fa l th rth With ıc nt ın the ıo sph re the atm ph re become rapidly mo e t nuous At ight of 100 km the number of m lecules per unit olume ıs about 1 000 000 tıme le s than ıt ı at the surfa e of the earth whe eas at 200 km the figure ı perhaps 10 It mu t be real zed h wever that although the atm phere ın the ı osph s extremely tenuous compared w th th t at the gr und nevertheless a good deal of atm sphe e st ll ı ts at ıono pherıc le els Thu at a h ıght of 100 km th r rema n me 10 atm spher c molecule per ub c meter and f the e a l a t on of o ly about 10 are ı nt ed In the ı n ph r a p rtı ular molecule ıs able to tra el a mu h greate dı tan bef re llıdıng with another m l ul Whereas the mean free p th of a m lecule nea the surface of the earth ıs about 10 met r ıt ıs about one tenth of a meter at a l eight f 100 km and perhaps 100 meters at a he ght of 200 km In th e h gh ıo ph r a mole ule tr els m n kıl meter bef r coll dıng with another molecule At heıghts above 00 km how eve the e r ma y nkn w features of th atm s pher Thes re under current ınvestigation w th th d of artıfıcı l satell tes Se ATMOSPHERE METEOROLOGY RADIO-WAVE PROPAGATIO

[H G B]

Bibliog aphy R Bolgı no (d) Inter tı nal ympo um o flu d mechan s m the ıon phere *J Ge phys R ea ch* 64(12) 2037 2238 1959 J A Fleming (ed) *Te restrıal Magnetısm and El trıcıty* reprı t 1949 G P Kuiper (ed) *Solar Sy em* ol 2 1954

Ion permeable membrane

A f lm o heet of s bst nce hı h ıs pref ren tı lly pe m abl to som species or type of ı n Thı s lect ıty ıs n ually exhıb ted durıng elec trı al tr nsp rt f ı er s the m mb nd r n lect ıcal p tent l but the term also applied to m mb a es sh wı s le t e m t nsp rt und r pressu e or oncentrat n grad nts Tech n q e based th e membran s m y b u ed to de mıze w t or th r l nts to epar te var us o specıe r t carry ut electrochem al re t s wh le ı latı g th pr du t f re t o

Principles M mbra es howın o l ctı ıty n le trı al t n p rt a e d to be p m ele tı a d are usually compo ed f s bst nc s hav g ı n e l a g pe t es Su h sul ta s h s a chem c l st u ture o p t ng fi ed ha g s tes f on charge type, posıtı e o neg t e, e h ne of wh ch ı ele t ı lly l ala e d l y a t nt r ı f or po t cha ge t pe Th unte n ad ly e ha ged fo an the mob l f ım la ha ge type x st ng th l t n urr ı d g and perme tıng the ıon e cha ge m t l The numbe of mobile ı f om th ol ı o h ch may e t n the membr e ph ın add t n t ll e e nter ı s s go erned by D nn typ membr e eq lıb m S DONNAN EQUILIBRIU ION EXCHANCE

After establ hme t f a Do n q l b ı m th o ent ı n f o ha g type f o w th n the

The hot filament gage is mo t useful at pressures less than 1 micron (μ) Use is limited because the filament will burn out if the pressure rises much above 10 μ Unwanted chemical reactions or ad sorption may take place on the heated surface

In the cold cathode (Philips) ionization gage a high voltage is applied between two electrodes Fewer electrons are emitted but a strong magnetic field deflects the electron stream increasing the length of the electron path and thus increasing the chance for ionizing collisions of electrons with gas molecules This type is widely used for pressures of 0 01–10 μ

In another type of ionization gage the gas is ionized by high energy alpha particles emitted by a radioactive source such as radium

All ionization gages must be calibrated for the gas to be measured because different gases have different ionizing properties Accuracy of 10% of full scale value is attainable [B D H H C P]

Ionization potential

The potential difference through which a bound electron must be raised to free it from the atom or molecule to which it is attached In particular the ionization potential is the difference in potential between the initial state in which the electron is bound and the final state in which it is at rest at infinity

The concept of ionization potential is closely as sociated with the Bohr theory of the atom Al though the simple theory is applicable only to hy drogenlike atoms the picture furnished by it conveys the idea quite well In this theory the allowed energy levels for the electron are gi en by

$$E = -k/n \qquad n = 1\ 2\ 3$$

Here E is the energy of the state described by n The constant k is about 13 6 electron olts for atomic hydrogen The energy approaches zero as n becomes infinite Thus zero energy is associated with the free electron On the other hand the most tightly bound ca e is given by etting n equal to unity By the definition given above the ionization potential for the most tightly bound or ground state is then 13 6 electron volts The ionization po tential for any excited state is obtained by e aluat ing E for the particular value of n associated with that state For a further discussion of the energy levels of an atom *see* ATOMIC STRUCTURE AND SPEC TRA ELECTRON VOLT

The ionization potential for the removal of an electron from a neutral atom other than hydrogen is more correctly designated as the first ionization potential The potential associated with the re moval of a second electron from a singly ion ed atom or molecule is then the second ionization po tential and so on

Ionization potentials may be measured in a num ber of ways The most accurate measurement is ob tained from spectroscopic methods The tran itions between energy states are accompanied by the emission or absorption of radiation The wa length of this radiation is a measure of the energy difference The particular transitions that ha e a common final energy state are called a eries The series limit repre ents the transition from the free electron state to the particular tate common to the series The energy as ociated with the eries h a transition is the ionization energy

Another method of measuring ionization poten tials is by electron impact Here the minimum en ergy needed for a free electron to ionize in a colli sion is determined The accuracy of this type of measurement cannot approach that of the pectro scopic method *See* CHEMICAL STRUCTURES ELEC TRON CONFIGURATION ELECTRONEGATIVITY

[C H M L]

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Ionosphere

A succession of electrically charged (ionized) layers in the earth s atmosphere above the tropo sphere and stratosphere zones In the tenuous outer fringes of the earth s atmosphere incoming radia tions from the sun ionize the gases pre ent The free electrons thus made available render the outer mo t portions of the earth s atmosphere electrically conducting This part of the atmosphere is kno n as the ionosphere and extends from a height of about 60–80 kilometers (km) up to heights in exces of 1000 km

Bases of the concept The existence of the iono sphere was first suspected from studies of the mall variations that occurred in the earth s magnetic field These could be explained in terms of electri currents in an electrically conducting upper atmo phere The existence of the iono phere became much more certain however after Marconi had succeeded in transmitting radio waves acro the Atlantic Some means were required to explain how the radio wa es managed to surmount the curvature of the earth The possibility that an electricall conducting ionosphere could act as a mirror f r radio wa es was the most obvious explanation of Marconi s observations During the 1920s experi ments were made to detect the existence of the ionosphere by what would now be called radar techniq es In this way the existence of the ion sphe e was independently established by E V Appleton and M A F Barnett in England and by G Breit and M A Tuve in the United States In the early experiments reflection of radio waves a obtained from what is known as the E region of the iono phere at a height of about 100 km Later ex periment at h gher r dio frequencies showed that it i po il le to penetrate the E region of the iono sphere and that reflecti n is then obtained from a higher region known as the F region at heights varying from 200 t 500 km At still higher rad o frequencie even th F reg n i pe etrated without

membrane will exceed the other by the concentration of the counter ions Therefore the proportion of any electrical current crossing the membrane carried by the ions of the most numerous charge type may be very high and the electrical mass transfer of these ions in the direction of the oppositely charged electrode correspondingly high Membranes whose fixed charges are negative and counter ions positive are under an electrical potential preferentially permeable to cations tho e having positive fixed charges and negative counter ions are preferentially permeable to anions

The electrical transport number of one charge type of ion in a membrane depends on the electrolyte concentration of the surrounding solution in equilibrium with the membrane This is a necessary consequence of the Donnan membrane theory and leads to the important practical consequence that the selective ionic permeability of the membrane decreases as the external electrolyte concentration increases At sufficiently high concentrations the membrane will have no electrolytic selecti ity and will serve simply as a diffusion barrier Membranes with the highest fixed charge concentration will be selective at the highe t external concentration

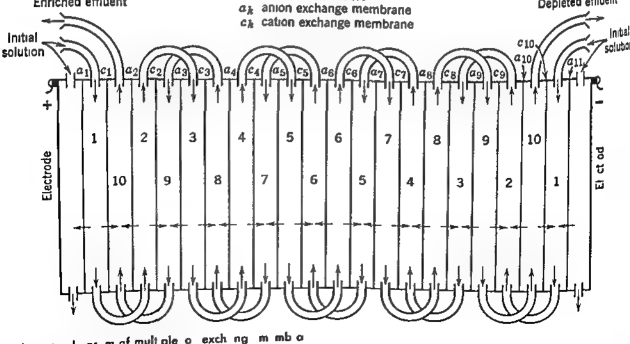
In addition to the electrical transport of ions across ion permeable membranes electroosmotic transport of water or solvent also takes place with the net tran port being in the direction of the counter ion movement The amount of water tran ported per faraday will depend on the properties of the ions simultaneously tran ported and on their transport numbers in the membrane Thus the net water transport i a maximum at low external solution concentrations

Measurement of transport numbers within the membranes can be made by direct measurement of ionic tran port in electrolytic cells or by mea ure ment of membrane potentials across a membrane separating solutions of known and different electrolyte concentration The departure of the mea ured potential from the ideal Nernst potential is a mea ure of the transport number of the counter ions in the membrane

Membranes The physical properties of ion permeable membranes vary considerably Ideally they should be tough and flexible readily hydrated, yet good diffusion barriers Practical membranes for electrodialysis should have low resisti ity and are usually less than 0 025 in thick For analytical measurement of ionic activitie low resi tivity is not essential The membranes may be of heterogeneous or homogeneous phy ical structure and may be internally supported by inert material

The principle application of ion permeable membranes is to electrodialytic deionization using electrolytic cells having multiple compartments separated by the membranes as shown in the illustration.

Membranes labeled a_i are preferentially permeable to anions and tho e labeled c_i are preferentially permeable to cations Under an applied potential the ions in compartments 1 2 10 will migrate through the ion permeable membranes toward the electrodes into compartments 1′ 2′ 10′ Hence alternate compartments will be depleted and the others enriched as electrical current flows The alternate compartments may be joined as shown the current traversing the continuous streams n times where n is the number of unit cells A unit cell is defined as consi ting of



Schem t c d gr m of mult ple o exch ng m mb a l ctrod alys s ell Small hor zo tal r ows d te movem nt f o s betwe n c mpa tm nts

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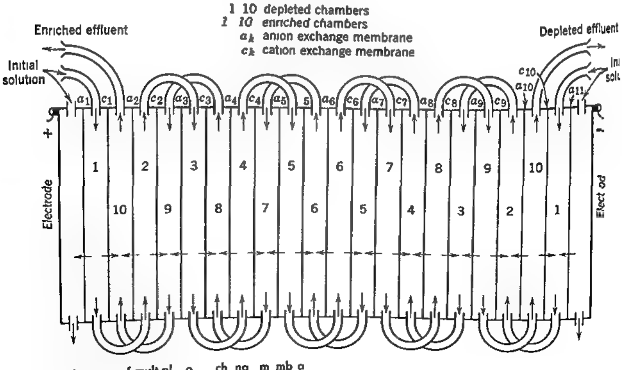

S hemat c d ag am f mult pl o ch ng m mb a ele t od ly c ll Sm ll h r o tal w d ate m vem t of ons betwee c mpa tm ts

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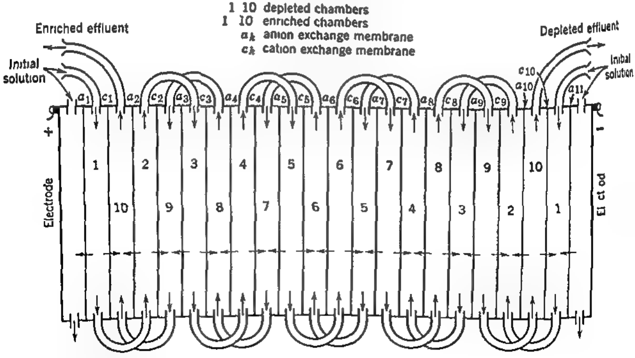


Schematic diagram of multiple ion exchange membrane electrodialysis cell. Small horizontal arrows denote movement of ions between compartments

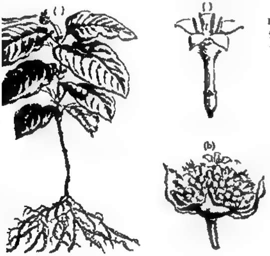
. d chamber and an adj ce t co centrat d ber with the rr n di g an on perme ble cat n p rmeabl m mb ane The lectr de bers a e f d ı depe dently to keep the l c e ctı n prod u par t fr m the c ted d plet d lectr lyte tream Se Di n ELECTROLYTIC CO DUCTANCE ELECTROPHO- SALI E WAT R RECLAMATIO

[A C W R.KU]

bliog aphy R. K nın *Io E ha g Res ns* d 19 8 F C. Na hod a d J S hubert (d) *Ex ha ge Tech l gy* 1956

ıcac

w pe enn al hrub half hrub f the tr p cal t ın B azıl and Col mb a. Se r l pe ı s a e d b t the d ıed r u nd rhizomes of *Ceph lis*



lp (C ph I n ch) ( ) Ent pl t (b) In- fl sc ( ) S gl fl w (F om A J K M I Th N t I H st ry f Pl t H lt)

p h a t ı t th m te l ecog zed as th u al d g. pec Med ally ıt sed p ı p lly as a met c a d e pecto ant S RUBIALES

[P D S]

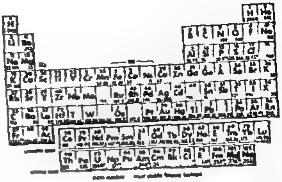
IR drop

Th pot u l d p d t tan e r a y p l m t (wh h t t f le tro- m t f) an lectr t. Thı pote t l d p by d fi t the p od ct of th r t e *R* of th l m t d th t *I* fl g th ugh t. Th *IR* d p es t ı th d ff e c f pot tı l bet ee the tw e d of th res t r I mpl d ect-cu nt c t ıta ı g batt ry a d n mber f e t a, the um f ll th *IR* d d th c r t (l d g that f th ı ı rn l t n e f th l att y tself) ıs eq l t th lect m t e f e f th b tt y Th mport t t th m sef l th lyt sol tı f lectrı l tw ks.

[J W.ST]

Iridium

Chemic l element umber 77 ıridium Ir ın the free state s a ha d white metallic substance



Uses At o dinary t mpe at es, ıridıum ıs the m st o ro ı n e ı tant leme t known It s used f ery high t mp r ture cru bles pe ti g ın n noxidızıng tmo pher fo f rna e windings, a d a an all y ng elem ent to t e gthen pl tın m

Chemical and physical properties The atomic n mbe f rid um 77 atomic weight 192.2, d n ty 22.54 g/cm meltıng p t 2443 C, boilıng po nt 5300 C, nd l ct c l r ıst ty 5 3 mı r hm pe c nt meter t 0 C. Rad o ct e so- t pe f th f ll wing m ss n mb a e kn wn 187 188 189 190 192, 194 195 196 197 and 198 The tabl ı otope of ı d um have the m u num be 191 d 193 The nat r l bu d n of the e r 38.5 nd 61.5% pect ly Irıd um ı n t tta ked by a y id ı ludı g aq a eg a A 30% rıd um pl ti m alloy pra tıc lly ıı luble ın qu g Fu ı n with alk l id zıng flu es s e s ry to c ert ırıdı m to a oluble form Dı sol tı n of r dum may l o be a ompl hed by fu g t with sodı m hlo de whıl tre t ng the m lt w th hl ı Th e t eme ın rt s of ırıd um rich ll ys eate pr blems the an lysıs a d refin ng Irıd m hıb ts al ce tates f 1+ 2+ 3+ 4+ nd p b bly 5+ d 6+ Th 3+ a d 4+ l a are the m t mm Iridium h tro g te dency to f rm c d nat n c m p ds

Metallurgical extraction O m d um bta ned n the t t n f pl tın m s fu ed w th zınc and sub ı e tly d g ted w th hydr hl rıc a d t n ert the m t ı l to a fi p wd Th s powde s th f ed w th an lk l oxıdızıng flux wh ch n erts th dıum t n a d solubl form Th p oced e ı ely quantıt t so that th nsolu bl e d e m t b recy led Varı s hydr lyt sep r t ıl bl t parate the ırıdı m f m th r m t l Oft th ın l bılıty of d m ın le d ed t parat ıt from oth r p ecı us m tal Th relat e lub l ty f amm n um bl dat w t m y lso b ed t ffect separ tı n. When he ted th omp d y ld m t llı d m Separat e not quantıt ı th l gthy cyclı g of ta lı g s equı ed

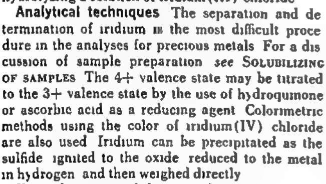
Principal compounds Iridium trichloride $IrCl_3$ is a green water insoluble compound made by treating iridium powder with chlorine at 500 C Sodium iridium(IV) chloride $Na_2IrCl_6 \, 6H_2O$ is a black water soluble crystalline solid made by heating a fused mixture of iridium and odium chloride in chlorine and then dissolving the re sulting melt in water Sodium iridium(III) chlo ride $Na_3IrCl_6 \, 12H_2O$ is an olive green water ol uble crystalline solid made by reducing a olution of sodium iridium(IV) chloride Ammonium irid ium(IV) chloride $(NH_4)_2IrCl_6$ is a red black relatively insoluble crystalline olid made by add ing ammonium chloride to a solution of sodium irid ium(IV) chloride Iridium trihydroxide $Ir(OH)_3$ xH_2O is a green black insoluble solid made by hydrolyzing a solution of iridium(III) chloride

Analytical techniques The separation and de termination of iridium is the most difficult proce dure in the analyses for precious metals For a dis cussion of sample preparation *see* SOLUBILIZING OF SAMPLES The 4+ valence state may be titrated to the 3+ valence state by the use of hydroquinone or ascorbic acid as a reducing agent Colorimetric methods using the color of iridium(IV) chloride are also used Iridium can be precipitated as the sulfide ignited to the oxide reduced to the metal in hydrogen and then weighed directly

For a discussion of the natural occurrence met allurgical extraction and alloys of iridium *see* PLATINUM *see also* OSMIUM RHODIUM [E A HA]

Iron

Chemical element number 26 iron Fe is the fourth most abundant element of the earth s crust (5%) It is a malleable tough silver gray magnetic metal It melts at 1540 C boils at 2800 C and has a



density of 7 86 g/cm The atomic weight is 55 85 each atom has 26 electrons and the four stable naturally occurring isotopes have mas es of 54 56 57 and 58 The two main ores are hematite Fe_2O_3 and limonite $Fe_2O_3 \, 3H_2O$ other ores are mag netite Fe_3O_4 taconite (an iron silicate) and siderite $FeCO_3$ Pyrites FeS_2 and chromite $Fe(CrO_2)_2$ are mined as ores for sulfur and chro mium respectively Iron is al o found in many other minerals and it occurs in ground waters and in the red hemoglobin of blood

The greatest use of iron is for structural steel cast iron and wrought iron are made in quantity also Magnets dyes (inks blueprint paper rouge pigments) and abrasives (rouge) are among the other uses of iron and iron compound

The free metal is obtained in bulk by reduction of the ore by coke Pure iron is difficult to obtain because other elements are held tenaciously a pure material may however be obtained by reduction of the oxide with hydrogen or by electrolysis The chemistry of the zero oxidation state is chiefly that of the alloys addition of trace impurities (carbon phosphorus silicon nickel manganese chromium and cobalt) has a marked effect on the properties of the metal *See* CAST IRON HEAT TREATMENT (METALS AND ALLOYS) IRON (EXTRACTION FROM ORE) IRON ALLOYS STAINLESS STEEL STEEL MANUFACTURE WROUGHT IRON

Properties of the metal There are several allotropic forms of iron Ferrite or α iron is stable up to 760 C The change to β iron involves primarily a loss of magnetic permeability becau e the lattice structure (body centered cubic) is unchanged The allotrope called γ iron has the cubic close-packed arrangement of atoms and is stable from 910 to 1400 C Little is known about δ iron except that it is stable above 1400 C and has a lattice similar to that of α iron

The metal is a good reducing agent and depending on conditions can be oxidized to the 2+ 3+ or 6+ state In most iron compound the ferrous ion iron (II) or ferric ion iron (III) is present as a distinct unit Iron (II) is found in simple compounds such as FeO FeS $FeBr_2$ and $FeCO_3$ in hydrated compounds such as $FeSO_4 \, 7H_2O$ $FeF_2 \, 8H_2O$ $FeCl_2 \, 4H_2O$ and ferrous acetate tet rahydrate Ferrous sulfate and ferrous ammonium sulfate (Mohr s salt) $(NH_4)_2SO_4 \, FeSO_4 \, 6H_2O$ have been employed as standards for oxidimetric titrations The oxide FeO and hydroxide $Fe(OH)_2$ are quite basic they react with strong and weak acids to form salts The ferrous compounds are usually light yellow to dark green brown in color the hydrated ion $Fe(H_2O)_6$ which is found in many compounds and in solution is light green This ion has little tendency to form coordination complexes except with strong reagent such as cyanide ion polyamines and porphyrin

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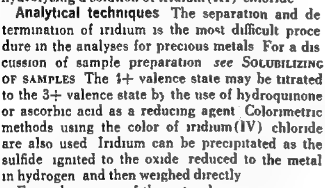

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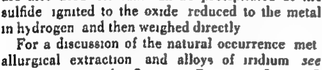

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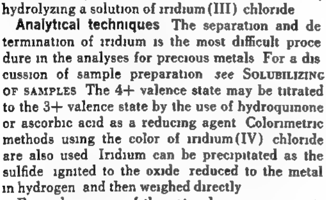

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tro g a ds b t th y re norm lly hydr ted a n Fe(NO)s 9H O nd f rric amm n um alum NH F (SO) 12H O Bec u e of mila ities n e a d ch rge al m n m i n nd ferric i n ha quite a l g u chem tr e alth u h f r ic hydr ide i n t amph ter The a hyd hl r des and b o- m des h e d meric p for e mpl Fe Cl a d ataly e certa n org n c rea tio s The hy dr ted on, Fe(H O) whi h i fo d i ol t o mb n w th OH F Cl CN SCN N C O and ther n t f rm coo d nati n om plexe A th c ntr t o f i n inc cases, more gr p c mb n w th e ch c t n u t l c mb na to ch s F Cl and Fe(CN) r re ched

Th f rrat o FeO wh ch nta n ir n in th 6+ idat on tate i bt ed by r a t w th st g d nts s ch s hypochlo ite n alka l e sol t Salts s ch as Na FeO and BaF O e re d ly p epa ed nd fa rly stabl S lu t s o t g the ferr t i n a e r ddi h p ple a d l yge l wly i lkal e m d a d rap dly in c d

An t rest g a pe t of r n h mi try is the rray of c mpo d w th bo d t b n Ce m t te F C is a omp nt of teel The cya d mpl e f both fe u a d f rr c re ery tabl d e n t tr gl m g et c n c nt ad s- t t t m t oo d t omple e Th ya de mpl f rm c l r d lt i cl d g th fam pru n bl e KFe (CN)₆ m d fr m f r o nd p t m ferrocy d K₄Fe(CN)₆ Th c mp d T rnb ll blu made from ferr u d pot m f r y d K Fe(CN)₆ i bel eved t be de t c l t p s an bl e Th re e m y c mpo d c ta g fi ya de g p a d ther gr p (h s NO CO SO NO NH d H O) bo t the r n The c m po d N Fe(NO)(CN) 2H O e u h m po d t be ed t t t f ulfide on

The th bo yl F (CO) F (CO) a d F (CO) lso ha i to-ca bon bo d I n pe t bo yl f rmed d tly by the act o of w th bo m de d p es re the th bo yl y the ed by d ect mea Th pe t c bo yl mp d ed a sou of p S ME L C RBONYL

Abo t 1950 w t pe f i mp d w s d sco e ed Cy l pe t d ca e t w th r n d t g d y l p t d yl F (C H) M y lt ti th f th mp d lled f oc l bl The t ct i th i f t m bet ee tw ymmetr l pe t g l g th b g g t m d th ame sa d h mpo d F h r m k bl th rm l t l t S O c O IET LIC CO TPOU D

M d t es f f rroc with b t t e t g p t hed t th g bo a e k n th h m t es m th l f g t th t f F r ic be i ed t th f oc m F (C H) d l t g th h been p pred S Lo N CKE Tr ITIO ELEME TS [J O E.]

Iron (extraction from ore)

I on is extr cted from ron ore and concentrates by pyr metall g cal p o s e ba ed up n the appli c t o f heat and redu ing ses At temperatures of 700–1100 C, r n o des s ch as hematite (Fe O) and m gn t te (F O) the principal i on beari g mi er l a e r ad ly reduc d t metal lic r na f llow

$$F\ O_3 + 3CO \rightarrow 2Fe + 3CO_2 \qquad (1)$$

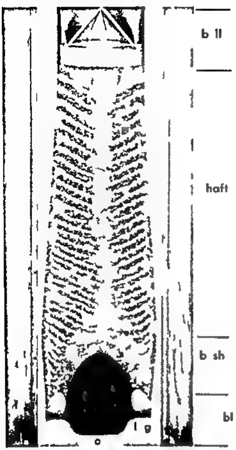
$$Fe\ O_3 + 3H \rightarrow 2F + 3H\ O \qquad (2)$$

M gnet te is s milarly red ced

Red cti n s car ied out blast fur ace and in so-c lled di e t edu t on pr e e The bl t f r nace pr ce produces m lten pig iro nta n n bout 4% c rb n a d a total of approx mat ly 3% f ma e e sil on a d pho pho u wh ch m st be la ly r mo ed n th onv r on of pig o nt teel the p n ipal o tlet fo ir n Direct pr e s s p rate at l wer temp r t re nd there f re p od c old red ed ron wh ch is relati ly free f c b n a d the metal noted abo These metal re form d a d ll y d with the iron at the highe tempe at re wh h pr a l e r the b tt m f the bl st furn ce The term d rect pr e im plie that th s old d reduced i an b u ed d rectly the p od ct n of teel by m lt ng a d w th ute ten r fi

The blast furnace process The bl st fur ace p c the mo t effic ent a d m t e on m cal m a yet d el ped f r prod c g large t nn ge of m lte p g i n wh h an be c t i to seful h pe refi ed i to teel Short p mit e f r n ces wh h we perated pr r t ab ut 1350 p d ed l w a b n d the fo m lle ble on c lled wr ght ir which ould be fa hioned i t eful a t cle by h ting a d h t wo k ng The pe t on of the hort f rnaces w int rupted per od c lly t rem e the lid met l whi h c tai ed mall pe nt ge of occl ded slag H ghe temp r t re mo e st gly educ n ndit n a d th l ng time req ed f r smelt ng r acti t o r in larg f rn s p oduc d c rb ri ed nd l quefied i o nd l qu d lag f m th r g g e d th fl Th pr d t n f l qu d p g n d sl g a c t o s pe ati n marked the beg ng f th bl t f rn c p cess Th tran t f om th p od t on f wr ght n t pig w the r lt f the d l pme t f quip- m t wh ch p ded mean f f cing t ng bl t f t deep b d f f el a d the p d t f c mb st pw d th ugh n ly g l mn bed f aw mate ial t g f c k d fl The bla t f rn t th f of a h tt f d ct d melt g ch mbe mp d o ga p od cer

Th g r l h pe d gement of th ch g bl t f rn h wn i Fig 1 h lf e t f a model f n ce I rd t a o d l m g of es h l f d p d per m b lity l d r h rged l yers Th dark



F g 1 A ra g m t of materials i f nace mod l

layers represent the relatively coarse coke and the white layers the charges of relatively fine ore This layered arrangement is inherent in finer size of the ore its steeper angle of repose and the flow of ma terial off the conical shaped bell when it is lowered to discharge the raw materials from the hopper shown at the top of the model Liquid iron and slag collect in a bottom cylindrical section called the hearth The lighter pear shaped areas near the top of the crucible correspond to combustion zones Preheated air is forced into these combustion zones through water cooled copper castings called tuyeres

An in erted frustrum of a cone located immedi ately above the hearth is known as the bo h The formation of molten pig iron and slag in the bo h permits a gradual reduction in cross secti nal area at lower level The upper part of the furnace called the shaft i conical except for hort cylin drical section Widening of tl e shaft at lower levels permits the charge to move downward with out mechanical bridging a it expand upon l eat ing Additional cro s ectional area at lower levels of the shaft al o permit a lower de ent of the charge and a longer re idence time at temperatures where ore reduction and other metallurgical re actions occur Similarly more area in the wider ecti n of the furnace reduce the elocity of the a cending ga e pr longing ga l d c ntact

Structurally the furnace con i t of a steel hell lined with fire l rick to con er e l eat The l o h and hearth are water co led t maintain the refract ry lining The trend is to u e carbon lining in the hearth and bosh and to in ert bronze cooling pl in the lining of the lower part of the haft Modern furnaces are about 28 ft in diameter in the hea h, are about 31 ft across the widest ection and taper to about 21 ft at the stockline An over all height of about 95 ft provides a working volume of about 50 000 ft³ Such furnaces consume 1100-1300 ton of coke per day and produce 1300–2400 tons of pig iron per day depending upon the iron content of the ore used the coke required per ton of iron and the physical character of the raw material Ore of high iron content reduces the amount of coke a d stone (fluxing materials) required per ton of pig Replacement of coke and tone with ore increases the weight of iron per cubic foot of charge An in crease from 50 to 60% in the iron content of the ore will for example introduce about 30% more iron per cubic foot of over all charge

Permeable charges permit larger volumes of gases to move through the stock column more uni formly without building up pressures which sup port the charge and prevent it from settl ng regu larly Under such conditions a larger volume of blast can be applied more coke can be burned the charge will ettle more rapidly and more pig iron will be produced In general beds compo ed of particles of uniform size will offer less re i tance to the flow of gases

The value of uniformity in the size of the coke has been fully appreciated for many years because coke occupies about 60% of the volume of the charge Pieces smaller than ¾ in are normally d carded for furnace use by screening the coke im mediately before charging Care is taken to blend the coals available to obtain a strong coke whi h will not fracture into small izes upon handling prior to charging or in the furnace

Size preparation of raw materials Since 1956 the large capital expenditures required to build new l last furnaces and the pre sure due to infla tion to increa e the productivity of exi ting fur naces have stimulated a pronounced intere t in the ize preparati n of iron ore and concentrate The depletion f high grade depo its has nece itated the benefi iati n of l w grade dep its and the pro duction of concentrates that must be agglomerated before they can l e i ed in the bla t furnace During agglomeration mall sizes are converted to larger lumps by the applicati n of heat which form poro mas e by grain growth and cau e slag l onding without complete fu ion Alth ugh the use of agglomerated c ncentrates is increa ing large tonnage of direct hipping ore containing 5? 60% Fe will l e a ailal le for at lea t e eral decades Thi ore can l e i ed effecti ely in the l la t furnace providing coar e es are cru hed to about ? in a d particle maller tl an ? in are agglomerated l y sintering Th i pr dure eliminate particles in a ize range whi h offers high re i tance to ga flow and al greatly red tl e am unt of fine ore ca i d off a flue d t

A rec nt development ı t ıncorpor t flux s ıch a calcıum xıde o m gn ı m xıde nto gglom ated m t r al ın the form of ı regul rly ıaped ter o sph rı l pellets Pellet are proıced by h at g w t ball mad f m fin ly d d d nc nt ates Th prod ctio of s lf fluxıng ag me ates may lead to two-comp nent charge cons stıng of coke and self fluxın agglom rates or t th ee comp nent charges of coke sc eened re and self flux ng ggl merate I comp rı on with th n ızed e cha g u ed ı the past these mo ı ıde l ch rg s of ızed mat rıal will make ıt p ss ble to bu n about 30% more coke per day per f ırnace a d to n r pr d ı t on accord ngly

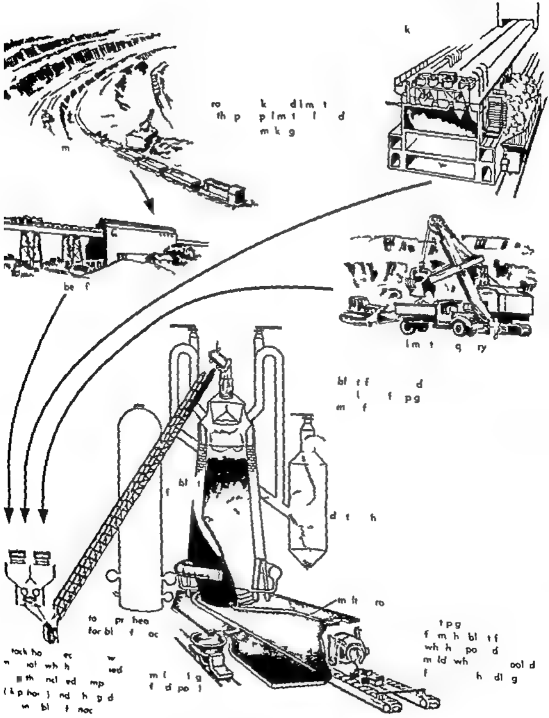


Fig 2 S ps l h bl t f no p oc ss f ir e t ctio (Am I a d St f I st t t)

The use of oxygen enriched blast containing balanced additions of steam is another promising development which will permit more coke to be burned in furnaces of all sizes This will be possible because less gas is made per pound of carbon gasified with oxygen enriched air and steam as shown in Eqs (3) to (5) Coke burning rates may be increased well in excess of 30% by the use of oxygen enriched air and steam in conjunction with sized iron bearing materials If the quantity of iron per cubic foot of stock is increased 30% by the use of richer ores and these high iron charges are then moved through the furnace 30% faster production will increase by 69% $(1.3 \times 1.3 = 1.69)$

Reactions in the furnace Heat and reducing gases are released near the base of the furnace by the combustion of coke Because air contains about 79% nitrogen N_2 and 21% oxygen O_2 combustion in a deep full bed can be expressed as follows

$$2C + O_2 + 3.76N_2 \rightarrow 2CO + 3.76N_2 + \text{Heat} \qquad (^{79}/_{21} = 3.76) \qquad (3)$$

The products of combustion when using dry air consist of 34.7% carbon monoxide CO and 65.3% N_2 $[(5.76/2.0) \times 100 = 34.7\%]$ Two moles of coke carbon require 4.76 moles of air If the air is enriched from 21 to 30% O_2 by the addition of manufactured oxygen the combustion reaction will be as follows

$$2C + O_2 + 2.33N_2 \rightarrow 2CO + 2.33N_2 + \text{Heat} \qquad (^{70}/_{30} = 2.33) \qquad (4)$$

With this degree of oxygen enrichment only 3.33 moles of blast will be required to gasify 2 moles of carbon C and the products of combustion will consist of 46.2% CO and 53.8% nitrogen

$$(2.0/4.33) \times 100 = 46.2\%$$

By the elimination of inert N_2 oxygen enriched air provides a means for burning C at faster rates for increasing the reducing power of the gas and for increasing flame temperatures

Air normally contains some moisture which reacts with carbon as follows

$$C + H_2O \rightarrow CO + H_2 - \text{Heat} \qquad (5)$$

Recent experience has proved that when moisture is added and higher blast temperatures are used to compensate for the heat absorbed by reaction (5) smoother furnace operation and higher productivity result The hydrogen H_2 and CO produced by reaction (5) dilute the N_2 and increase the reducing power of the gas permitting the ore to be properly reduced even though it descends more rapidly Oxygen enriched air has a similar effect

Substantially all of the heat for the process is either introduced in the blast which is heated to temperatures of 550 950 C or is released by the combustion of coke in localized zones before the tuyeres Nitrogen carbon monoxide and hydrogen which leave the combustion zone at temperatures of 1700 1900 C carry heat to the overlying column of stock Gases leave the top of the furnace at 1 200 C More permeable areas receive more gas and are thus heated to a higher temperature Efficiency of heat transfer as well as efficiency of reduction and other smelting reactions depends upon the degree of uniformity of gas flow through the stock column The recent trend toward the use of high percentages of sinter pellets and sized ore with the gradual elimination of all unscreened ore will increase efficiency and productivity and permit closer control over the composition of the metal

Control of pig iron composition The carbon content of the iron is fairly well fixed at about 4.0% because the iron is saturated with carbon However higher percentages of silicon tend to lower the solubility of carbon in iron Because all the phosphorus and about 75% of the manganese in the charge are recovered in the pig iron these elements are largely controlled through the selection of the ore Silicon and sulfur are controlled by adjustments in the temperature in the crucible and by regulating the composition of the slag through the addition of varying amounts of limestone An increase in the temperature of the hearth will raise the silicon and lower the sulfur content of the iron Hearth temperatures are regulated by the amount of fuel used by the temperature of the blast and by the addition of steam to the blast Eq (5) Variations in gas flow and in the transfer of heat from gases to solids result in uneven heating of the charge making it difficult to control the temperature of the hearth

Direct processes Although direct processes have been subjected periodically to extensive study research and investigation on a pilot plant scale since 1920 they have thus far failed to compete with the blast furnace in supplying an economical source of iron for steelmaking However the present outlook for such processes to succeed in more favorable localities is brighter than in the past Imported ores and concentrates of low gangue content are now more readily available for producing a solid reduced iron that will not produce excessive amounts of slag in steelmaking furnaces Techniques for reforming nonreducing hydrocarbon gases such as methane into CO and H_2 have been improved Substantial progress has also been made in the development of fluidized bed techniques which permit the flow of reducing gases through beds of finely divided ore or concentrates in counterflow processes which are more efficient thermally than older processes The generally high prices of steel scrap since World War II have stimulated interest in direct processes as a means for producing a cheaper source of metallic iron for steelmaking Current developments which show great promise in increasing the productivity of blast furnaces will have an important bearing upon the price of steel scrap and the future competitive position of steel scrap direct process iron and pig iron *See* CAST IRON COKE IRON IRON ALLOYS MINING OPEN CUT OR PIT ORE DRESSING

PYROMETALLURGY STEEL MA UFACTURE WROUGHT [T.5.J] 180

B bl o aph 1 W Frankl n Indu try look at d rect reduct Eng M n J 158(12) 84 93 19 U.S. Steel Corp The Mak Shap and T at e of St l th ed., 19

Iron alloys

All ys I ir co t n g th l ment m amo t ary g l m few pe nt t p thap a fu h 85% d d ff re ti ted f m a t ron nd te l by comm epta ce i th ind try F r p rpo es of n ence e th e n b gr uped by the r c m m l appl atio t th foll win e teg ries magn t all ys lectr l res tan e all heat res t g all corrosi n resi t ng all and th rm l expa n all s

The mbe f po bly u ful ll y a d th r hem l gradati s n rm At le t 70 000 so-called en in ri g all y n l ding both fe d n nf rr h been de ribed, and new es a e bei g added con ta tl Th d n h been lim ted t some f th bett r kn wn types of e h gr up these dent fied by trad names alth ugh t h uld be bor e mind that in ma y i t nces all s f th ame compo ti n ar l ble f m d fferent prod ers under the n mes. An ll y may be at t mes des ribed an unquali fied n me nd a s le mpos t n lth gh it r pres tat f series the m mbe f whi h re t pra t e m r pec fi ally ident fied b let t s mb Ea h of th m mbers a modifi ti f th rigin l mpos ti n and des gned t at f som p rt l r equ me t F m ple I l s i k l-ch m um all y contains app im t l kel 15% ch om um d e n. Th t mod fied n th f I n l X b th dd t n f m ll cont lled mo t f n. Fe al m m Al, t t m T a d colum b um (n um) Cb t mp t gth nd h d es nd t r d t u pt bl t g hardenin In the se f I on l W the properties ar com pa bl s those f I e n l X, alth h col m b m h been l mi ted l l 00 o th ther h d t in ab t 28 cobalt, Co nd 3% m l bdenum M a d ha dened w th al mi um a d t t n m lt exh b t good eep d rupt e p pert es t ll temperat es espec all t 1 00 F d a d h been sed f first tag tu b n blad g j t ft e es es. The I coloy p l col Incol T a d I coloy 901 h mpl f a series f mod fied all

Magnet c alloys Magneti all ma be broadly l fied n der tw he d g nretent e r m g et c lly soft d retent (perm nent) r m g etically h d s di ted n T bl l

Th soft all bec me m gnet zed a magnet fi ld, b t l d m g eti ed wh n th fi ld i emoved Th f m a t ro whi h th poo est t th i n k l ll ys, wh h re the best l ind th well kn wn lectri al l tool teel These soft all y fi d w dest appl t on n modern commun cation and electrical power equipment and a e the most important in the ba i of qu ntity prod ced Th y are ordinaril u ed n th wro ght t te

The retent e o hard all ys remain magnetized after appl ti n of a m gneti field Alth ugh pro duced in les r quantity they e the old f th tw groups These allo are mpl ed wher a con tant magn ti field s requ ed and where t i impract al to establ h an lectrom gn tic fi ld. Th are u ed in the wrou ht r ca t tate or re pr p red by the nterin proces wh ch i espe all u eful n makin mall magn t Some of the Alnico m be ther ca t or i t ed

Some allo especially f the soft gr up a well as ther magn tic m t rial pos e ertain fe tures th t make them pecul arl ited f pec fic applications F r e ample the perm abil ty f the allo s co taining about 30% ickel "30% iron, uch s the Carp nte Temperature Compen ator 30 varies li rly with temper tu e They a e u ed hunt in electri al a d th n truments to compen ate f amb nt t mperature ari ti n Other ll uch a P rm n a Conpern k and I operm xhib t relatively con tant perm ab lity dependent f field tre gth, and are wid l em pl ed n c mmunicati n rcuit

Alth u h th soft all ys a e gen rally used a sol d metal they ar som times empl ed in the ely divided condit n in co es in nd ta ces in t l ph and rad o-frequency rcuits whe e the min m ze edd curre t losses The f rrom gnet oxides are u ed fo mil purposes. Two impor tant dev l pm ts f recent ears are th ceramic perm ent m gn t m teri l uch s Ferr m g I and the pec ll proces ed and h at t eated 3% s licon ir n eth bitin cub o ient tion. S e MAG NETIC MATERIALS M G ETISM

Electrical resistance alloys These ll are best known a th h sting el m nt in uch famil i r h useh ld t ms a r d tion h ters electric r nges and toa t The most comm nl used al l y f r thi purpo the 80 20 n kel-chromium type It has an cell nt combinati f electrical and mech n cal p operties a d good res tance to x d t n t tempe atures up t 100 F

Th re re al o a number of r n-co t in ng al a li ted in Tabl 2 that find wide appli at n in thi fi ld Th most popular of these contain 60% n k l 16% hromium, the bal nce ron 38% n k l, 19% hrom um th bal iron and 22% chr m um 5% al iminum 1% b lt, the bal ance iro

For som ppli at n th la t type uperior t even the 80 20 n ckel-chr mium all y It maximum ope ti g tempe atu (pp ximatel 150 F) and it es trict are high and t l s a l g ser ce lif Because f a tendency in service to i ase length w th t m (grow) d a cel ti el low tre gth wh n h t, heatin el ment made f th all require good mecha i al upport.

The u e of oxygen enriched blast containing balanced additions of steam is another promising development which will permit more coke to be burned in furnaces of all size This will be po sible because less gas is made per pound of carbon gasi fied with oxygen enriched air and steam as shown in Eqs (3) to (5) Coke burning rates may be in creased well in excess of 30% by the use of oxygen enriched air and team in conjunction with sized iron bearing materials If the quantity of iron per cubic foot of stock is increased 30% by the u e of richer ore and these high iron charges are then moved through the furnace 30% fa ter production will increase by 69% (1 3 × 1 3 = 1 69)

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Direct processes Although direct proce ha been subjected periodically to extensive study n search and investigation on a pilot plant al since 1920 they have thus far failed to compet with the bla t furnace in upplying an economic source of iron for steelmaking Howe er the pre ent outlook for such proce ses to succeed in m favorable localities is brighter than in the pa t Im ported ores and concentrates of low gangue conte are now more readily available for producing solid reduced iron that will not produce exce amounts of slag in steelmaking furna e Tec niques for reforming nonreducing hydrocarb ga es such as methane into CO and H_2 have be improved Substantial progress has also been ma in the development of fluidized bed te hni which permit the flow of reducing ga es throu beds of finely divided ore or concentrates counterflow processes which are more effi ient th mally than older proces es The generally hi prices of steel scrap since World War II have sti ulated intere t in direct proces es as a means f producing a cheaper source of metallic iron f teelmaking Current developments which sh great promise in increasing the productivity blast furnace will have an important bearing up the price of steel scrap and the future competiti p itions of steel crap direct proce s iron a pig iron *See* CAST IRON COKE IRON IR ALLOYS MINING OPEN CUT OR PIT ORE DRES

PYROMETALLURGY; STEEL MANUFACTURE; WROUGHT IRON. [T.L.J.]

Bibliography. J. W. Franklin Industry look ... *Eng. Min. J.*, 158(12):84–93, 1957; U.S. Steel Corp., *The Making, Shaping and Treating of Steel*, ... 1957.

Iron alloys

All y f i on o ta n g th eleme t i am unt ... ying f om a f w per e nt to pe hay ... high s 85% and diff ntiated f m ca t iron a d teel by ... mmo a cept nce n th nd try For p po e of co ... ence they an b grouped by the ... me al applic t ... n th following categ ie magn ti all y ele t i al r ta c all ys h at ... ti g all y ... ro ion esi t ng lloy and th rm l expan n ll ys

The numb r f p bly u l l all ys nd th r chem al g ... en ... At l a t 20,000 o-called ng eering all y ... cl d ng both fer ... ou h been d bed and new ... es ar be ng added o tantly Th s d ... ha been l mited t ... m f the better kn wn type ... ch g p th ar dent fied by t ade ames ... gh t sh uld be born n mind that n m ny ... lloys of the am mp sit n ... bl ... der the ames An all y may be at t me descr bed by an quali fied nam d gle omp t alth ugh it ... pre tati e f a e ... th memb ... f wh h ... n pact e mo e ... fi ally dentified by ... numb r E h f the m mb rs ... m d fi ati n f th ... g l c mpo it n nd s d g ed to s t sfy s m p rt ula ... q em nt F r exam pl I n l i a k l ch m ... lloy nta n g app x m t ly 77% n k l ... 7% Thi m d fi d th ... f l on l X by the dd t ... f m ll ... ntr ll d amo ... o F l m m Al tit ni m Ti nd ol m bi m (n b um) Cb t mp ... gth d ha d ... nd to r nd ... eptible t ge hard ni g In th ... of I ... l W the p p ... ar m p r bl to th of I ... l X lth ugh ... l m h b n lim n t d ... 1 00 th other ha d ... ta n ab t 28% ob lt Co ... d 3% m lyb d m M ... d r h d d with lum m nd t ta m It e hib t good ... ep a d ptu propert at ll t mpe atures espe lly ... 1600 F a d ... d h s b en ed fo ... tu bi e ... ad g n jet a ... ft g n Th l ol y group I ... l y I ... l y T and I ... l y 901 th r e ple f ... I mod fi d ... ll ys

Magnetic alloys Magn ti ll y may be bro dly ... fi d nd tw h ad g ... r m g et ally oft a d ... (p ma nt) ... ti ally h d ... d t d in T bl 1

Th ... ft lloy be ome m gn t ed in a m gn ti fi ld b t a e ... ly d magnetized when th fi ld ... mo ed Th ... ag f m a ... h h ... th poo est ... th ... kel all y ... the be t ... nd ncl d th well k ow ... l ... Thes oft lloys find wid ... ppl a ti n n modern communi ation and el ctr cal powe equipment and are th m t important n the ba s f quant ty produced They are rdinar ly u ed in the wr ught t te

Th retentive r hard all ys r mai mag tized after appl cati ... f a magnetic f ld Alth ugh pro du ed in le er q ant ty they are the older f the tw gr up Th alloys ar empl yed wh r a c n ta t magnetic fi ld i r quired and where it i mpractic l t establ h an elect magnetic fiel l They re ed in the wr ught r ca t state or are p epared b th nt ring proce wh h i e pe cially u eful in mak ng sm ll magnets Some of the Alnic s may be th r ca t r inte ed

Some all ... especially of the s ft group ... w ll ... oth r magnet ... material po es certain fea t res that make them pecul arly uited f r pecific appl cat ... F r x mpl the p rm al l ty f th alloy co tai ing about 30% n ckel 0% ir n s ch as the Carpent r Temp rature Compen at r 30 varies l ne rly w th temp ratu ... Th y r u ed a ... electri al and ther in trum nts to ompen te f r ambient tempe at ... ar at n Other alloy uch a P rmi a Conp rn k ... d I p rm e h bit a relat ly ... n tant perm abil ty and p ... dent f field tre gth and ar widely em pl yed in commu icati n ... t

Alth ugh th ... ft alloy are g ... er lly ... ed a s l d met ls th y ar ... m time employed in the finely di ided cond ti ... in core ... indu t nces in telephone and rad o-freq u ncy c rcu t wh re th y m nimi e eddy c rr nt l ... es The fer ... m gnetic ox de a e u ed f r ... mi lar pu po es Tw imp r ... t devel pments of ... ec nt year ... re the ceramic p rm ... t magnet m ter al ... h a Ferr mag l and the specially p oce ed and he t tre ted 3% s l ... n i on e hib ti g cub c or nt ti n S MAG NETIC MATERI LS MAG ETIS ...

Electrical resistance alloys These all ys are best known ... s the h ati g el ment ... i ... ch fam l ... h u eh ld item as ... d ... t on heat r el ctric anges and t a t rs The most ommonly u ed al loy f r th pu po e i th 80-20 nickel-chr mium typ It h s an e ellent ... mb nati n f electrical and mechan al p opert ... and g d ... t n e to o d t n t tempe at ... s up t 2100 F

The r also a number f i on-c nta ing ... l y ... l ted n Tabl ... that find wid pplication n th field The m t popul r f th e o tain 60% n ck l 16% h omi m the bala e i on 38% ... k l 19% h om um the balan ... and 27% ... hr m um 5% alum num 1% c balt th bal a ce i o

Fo ... me appl at ns the la t type ... pe ior t e en the 80-20 nick l-ch m um alloy Its maximum perati g t mpe ature (approx mately 2450 F) ... d its e ... t ... e h g l e a d t ha l nge ... ervice l f Becau e f ... tend ncy ... rs e t ... a e n l ngth w th t m (gr w) nd a r l ti ely l w t ngth when hot h at ng le m t m de of th all y ... g od me ha al pp rt

Table 1 Magnetic alloys

Name	Percentages								Remarks
	Fe	Ni	Co	Cu	Al	Ti	Si	Other	
Hard alloys									
Alnico I	Balance	21	5		12				Wide range of applications
Alnico II	Balance	17	12	6	10				High *BH* product
Alnico III	Balance	25			12				Can be cut and ground without chipping; low cost
Alnico IV	Balance	28	5		12				High coercive force
Alnico V	Balance	14	24	3	8				Oriented; highest *BH* product of known alloys
Alnico VI	Balance	15	24	3	8	1.25			Oriented; high coercive force; low residual magnetism
Alnico XII	Balance	18	35		6	8			Highest coercive force of any Alnico
Cunife	20	20		60					High coercive force; machinable and ductile; high cost
Indalloy	Balance		12					17 Mo	Sintered product
Vectolite								30 Fe_2O_3, 44 Fe_3O_4, 26 CoO	Highest coercive force of any material except Alnico XII; sintered material; light weight
Ferromag 1								BaO $6Fe_2O_3$	Extremely high coercive force; ceramic type; lightweight
Soft alloys									
Puron	99.95								Magnetic standard
High Si Iron	Balance						4.5		Power distribution, audio transformers
Cubex	Balance						3		Cubic oriented
Low Si Iron	Balance						1.0		Intermittent duty motors, relays
Hipersil	Balance						3		Transformer cores
Nicalloy	Balance	47							High permeability, power transm[illegible] [illegible] field
Permalloy	Balance	78.5							Sensitive direct-current apparatus, relays; high permeability; low hysteresis loss
4 Mo Permalloy	Balance	79						4 Mo	High frequency and electrical apparatus; high permeability and resistivity
Hiperco 35	Balance		35					1 Cr	Electric motors and generators; high saturation
Permendur	Balance		50						Apparatus operating at high flux density; high permeability at high flux density
Vanadium Permendur	Balance		49					V	A[illegible] very high saturation and [illegible]
Perminvar	Balance	45							M[illegible] transformers; high and constant permeability
Isoperm	Balance	40							High [illegible] constant permeability
Supermalloy	Balance	79						5 Mo	C[illegible] transformers; high permeability
Mu Metal	Balance	74						5 C	[illegible] audio transformers [illegible] high permeability
Carpenter Temperature Compensator 30	Balance	30							[illegible] temperature [illegible] compensat[illegible]
Conpernik		50							High [illegible] constant permeability [illegible]

T 2 Elect ical resista ce alloys

N m	F	C	Ni	Co	Al	Oth	R m k
			Pe ntages				
Alcres	B l ce	1			5		Res t. n d t n t 100 F
Al hro	Bal n	16			5		Res t. d t n t 100 F
Alu h om O	B la ce	30			5		Res t xid ti n t 100 I
B l o	B l e		0				Self regul tors l y t peratu e
Nicl m A		0	80				Res ts x d t n t 100 F
Chrom l C	B l ce	16	60				Res t 1 t n to 1800 F he vy d ty rheostat.
							Res ts d tion t 1100 F
Chromel D	B l ce	19	3				Coppe l ted e t n e ll y f seal ng in l ad n lect l g t t l lts and r d o t les
D m t	Bala ce		46				
F rropyr	Bal ce	7			7	1 Mn + S	Res ts datt 100 F
Ill m G	6	22	58			6 Cu 6 M	Res t nce ll y t ses rely rros t m spheres
K th l A	B l ce	23			6		Res ts d t t 100 F
Smith 10	Bala ce	38			8		Res ts d t t 100 I
T ph t C	Bal n e	1	[illegible]				Res ts x d t t 18 0 F

A Fren h all y by th m contains 25% ir bala ce k l d is used i lt ge resi tors.

In the elect cal a d lectr n c field the all y d the p fic ses s me f wh ch a e ind c ted Table 2 F x mple the 70% ck l 30% pe u ed i th rmom t r bulb and oth r appli t n q i ng h gh temp ratu e ffic nt f t n e a ll y ntaini g 60% n kel 16% h m um a d th bala e i on s pa t ula ly ted f h y d ty rheo t ts b c u e of it ab l ty t ith t d h gh o rl ads Se RESISTA CE, ELECTRICAL RESISTANCE HEATING

Heat resisting alloys In the choi e f alloys for igh t p rature s r i h m cal re sta ce i s t f th req r me ts Not only m t the m a tal s b ta t ally etain t g al id nity in the tmo ph e nd t th temp t f op ati n b t it m t al p ffi nt t ngth and hock t e t meet rni e qu m ts The t rm h gh temp t e erv e imple d ff rent th rmal cond t o b t f r th alloy d u ed il ect a m m m t mp ratu e f 1000 F ha b ch n Ab e thi p t th t nd rd Am ri a Ir n and St l I tit t (AISI) d t nle teel a ith t appl c bl they p e lm tat o s n me h i l p p ties

F m ny ye r ll y l gh ni k l ch om um d c l lt w r kn wn nd empl y d in the ch mi l d try but du Wo ld Wa II n d d ma d f ll y t w th t nd h gh t mp ratur f a h ppl ati n a xha t u p r h ge ft g e lt d n th de l pm t f wh t tod k w h gh t mpe tu m tal som f wh b s e d bed T bl 3 Th b adly cla s fied n ba e balt ba or n k l base d pe d g upon th pred m at ng l m t Som mployed n the ast tat th r e w o g ht d st B the s m y be util z d th th w ght a t f m

D l y 4 786 d th R fract l y re e am ples f th fir t l They h g d t ngth up t b t 1350 F d t f t ry x d t n es t a e t 1500 F and find th ir prin ipal ppl ca t n s t rbi e blades h o d ng (I at l (di g) a d t l o f jet eng nes

The cobalt ba all y with t d temper t res up to about 2100 F The r ex ellent trength a l id ti n a d c rr ion re tan e at the h gh temper t res mak th m s itai le f r per harg r buck ts and nozzl vanes Their high t however pre nt th r u e fr m b ng eco om c l unt l temper tures in excess of 1300 F ar e ntered

The n ckel b e lloys ha e c llent ox dat a d corro on r si tance up t 2 00 F The Inconels (N m n s in England) a e ad antageou in cycl h at ng and cool ng ervic wh re larg tem p ratu grad ent ex t Some ar p ec pit ti n h rd n g and de el p e y high el ated t mper tu e trength The Ha t lloys co t n rel ti ly l rge mou t of m lybden m and find e pe ial se in hem l equipm t that re ated in cor ro en onm nts

Corrosion resisting alloys The t rm c o on t g a ge tall n ed n th e tion r the e ta to attack by l quid a d ga s other tha a xygen Th tnt s ty of h att k dep ndent up n many f cto s for ex mpl the all ys c nc ned th p t cul med um nder on d at n c at ation and id ng r redu ng nd tion A larg numb r of th all y on d ered s c rro on res ta t ntain on in am unt ary g f m 2% t 50% N kel and ch o m m a comm n tit nt tog ther w th 12 1% m lybde um h lt pre C tu g t n W nd s l n C

Be u e of th many f t rs inv l d n ngle all y i a a l bl th t w ll d q at l e t all l rm of o i n There h s b large v r ty f lloy mp t u ed b t only a few e d crib d in T bl 4 It i oft n po s ble to find th t w ll t l t app x mat ly at fy a y g n t f om n l req i m ts F exampl

Duriron a cast silicon iron alloy (15% Si) is widely used in reaction kettles for handling acids and alkalies but it is quite unsatisfactory in resisting hydrochloric acid

Durichlor another cast silicon iron alloy of approximately the same silicon content and containing molybdenum may be used to resist this acid In like manner Hastelloy C which may be cast or wrought is noted for its excellent resistance to hot and cold solutions of most highly corrosive mineral acids

Many of the corrosion resistant alloys are heat resistant and the borderline between the two groups is often not clearly demarcated *See* CORROSION

Thermal expansion alloys Table 5 lists a few important members of a group of iron containing alloys having unique thermal expansion properties

Table 3 Heat resisting alloys

Name	Percentages					Form in service	Upper limit of service typical applications
	Fe	Cr	Ni	Co	Other		
					Iron Base		
A 286	Balance	15	26		0 2 Al 1 15 Mo 2 Ti 0 3 V	W	1300 F turbine blades afterburners
Discaloy	Balance	14	26		3 Mo 1 75 Ti 0 2 Al	W	1350 F turbine wheels and disks bolts
Incoloy	Balance	20	3		0 5 Cu 1 5 Mn	W	000 F resists sulfur attack and green rot
Multimet	Balance	21	20	20	3 Mo 3 5 W 1 Cb + Ta 0 15 N	C	1500 F turbine blades jet and combustion chambers
Refractaloy 26	Balance	18	37	19	3 Mo 3 Ti 0 3 max Al	W	1450 F turbine blades and parts
					Cobalt Base		
Haynes 21	2 max	28	3	Balance	6 Mo 0 3 C	C	2100 F turbosupercharger buckets
Haynes 25	2 max	20	10	Balance	14 W 1 5 Mn 0 15 C	W	1800 F turbine blades afterburner parts
S-816	4	20	20	38 min	4 Mo 6 W 4 Cb	W C	1500 F turbine blades
					Nickel Base		
Hastelloy X	Balance	2	45	1 5	9 Mo 0 6 W	W C	00 F jet engine tail pipes afterburner components turbine blades
Inconel	Balance	15	74		5 Cu	W C	00 F exhaust manifold afterburners
Nimonic 90	5 max	20	Balance		1 5 Al 5 Ti	W	1400 F turbine blades afterburners
René 41	5 max	19	Balance	11	1 5 Al 10 Mo 3 Ti 0 01 B	W	1800 F turbine blades afterburners
Udimet 500	4 max	18	Balance	17	3 Al 4 Mo 3 Ti	W	1750 F gas turbine components
Waspaloy	1	19	Balance	14	3 5 Mo 2 5 Ti 1 2 Al	W	1900 F turbine blades afterburners

W wrought C cast

Table 4 Corrosion resisting alloys

Name	Percentages					Remarks
	Fe	Cr	Ni	S	Mo	Other	
Alloyco	Balance	20	29	3	3	4 Cu	Acid and alkali resistant pumps valves
Durichlor	Balance		1	14 5	4		HCl resistant
Duriron	Balance			14 5			Acid (except HCl) and alkali resistant
Hastelloy B	5	1	Balance	1	8	5 Co 1 Mn 0 4 V	Resists HCl and boiling H_3PO_4
Hastelloy C	5	16 5	Balance	1	17	2 5 Co 4 5 W 0 4 V	Resists SO_2 H_3PO_4 and Cl_2 and H_2SO_4 at high temp
Hastelloy D		1	Balance	9	1	1 5 Co 3 Cu 9 25 Si	Resists HCl and H_2SO_4
Illium G	Balance	2	58		6	6 Cu	Acid resistant (including H_2SO_4)
Pioneer Metal	Balance	5	3		5		Acid resistant
Worthite	Balance	20	4	3	3		Resists H_2SO_4 and weak HCl

T ble 5 Th rm l-e p lon lloys

N m	P ce tages					Coeff t of expan n	R n ks
	Fe	C	Nt	Co	Otle		
I	Bala ce		36		0 15 C	Low	B t. l ther st t. l ngtl t. dt l m ng tapes
K a	B la ce		29	17		Som a glass	Vacu n t bes
N l a	B l ce		36			Low	Bun t. ls tl most. t. l ngtl tand rd m as tring tapes
N -Spa C	B l nce	5 5	4		4 T 0 6 Al	Con ta t nodul f l t ty	
N Sp Lo 5	B l ce		5		4 Ti 0 6 Al	Low	
N Span-ll	B lan	9	29		4 Ti	Hgh	

Th all y of the In ar type nta g bo t 36% *nickel the b lan t o* ha e an ext emely low e ffi nt f therm l exp They a e sed as ods a d tap s f geodet wo k c mp n ating pend l m b l n wh els i lock d watches and in del c te in t um nts They a e al m pl y d whe l w xpan n all v ope t with y high e p s ll y to a m em nt with t mp rat r cha ge a in b netal th rm l t bes nd r d a d tube rm ed n temp ra t r g lat r

Of especi l t e t th N Span a n f al l y Th on t kel ge ha d n lloys t in ng ab t 2% tit n N Span Lo eth b is l w oeffi e t f exp io N Sp Hi s the *e nd the* c effi i nt h gh A th rd Ni Sp C h a n t nt mod l f ela t cit a d u ed for sp i g n *pr n tr ments f r* hair p i i k s d watch d l r b u d n g et b s.

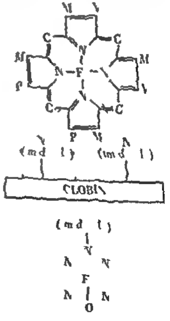
I the m n f ctu of a t u type of a u m t les wh re l m t b m d b rw gl a d m tal p l pa o h t t s a nts l n th lloy mployed mely tl t the e p urv s b m l to that of gl s a d th t th y e h b t h gh d g ee f thermal shock K p t a ll y p e i g thes p pe t A t appl at n of th all y its u e fo th m u t g g l d d m s l d ne m d *f Pr oce ss* the new fam ly of y t ll ne m t r l n d f m gl S THERMAL EXPANSIO l ALLO CAST IR N STEEL WROUGHT IRO [J J E R F]

Iron metabolism

Th m t bol m f r n di c s ed n th rticle with r spe t t ts r le in the ryth cyt red blood ll a d ts ab pt f m the i t stin l tr ct

Erythrocytes The d ell f bl od c n tit te abo t 40–50% f th total blood. The mamm l n e yth oc t t pp x m t ly 32% hem glo-b n 60–65 ate nd bout 8% t m the me h w k w thi hi h th hem gl bi s t t m t ly ld Th yth yt f med i th d b e m rr w nd p s th gh ev l pha e b fo e tran e nto the blood The phy ol g cal stimulu f r the prod ct on f *erythrocyte* m a l ering f the xyg e ntent f the blood in the bone mar *row* Th r po e of th l ne marrow con titutes n f the mo t important a p ct f a clim tiza t on t l le t h gh altitud s *The e ythrocyt s are* u derg g *continual* d nt g ati n mo tly in the ple n b t to me e te t in the bon ma r w and ther ret c loe d thel al is su capable of phag ocytic act on The br akdow of hemogl bin in *thi p ce l ad t the release of iro and th f* mati n of b le p gments The a erage l f pan f e ythrocytes is ab ut 1 0 d *y f r man 100* days f r the d g a l 3? day fo th ch cken S HEMATOPOIESIS

H moglob the e p ratory p ote n of vertebrat erythrocytes is a c njugation of an ir n



H m gl b f gments

H m gl b f gm ts (A Wh *P H* dl E L *Sm th D St tte P* pl f B o h m stry M G w H ll 1954)

porphyrin compound (heme) with a basic protein (globin) Four atoms of iron and four heme groups are present in the hemoglobin molecule

The porphyrins are all derivatives of porphin a ring structure compo ed of four pyrrole groups linked by —CH= (methene) bridges The ferroprotoporphyrin of hemoglobin contains methyl groups (M) in positions 1 3 5 and 8 (see figure) vinyl groups (V) in 2 and 4 and propionic acid groups (P) in 6 and 7 In each of the ferroprotoporphyrin groups of hemoglobin an iron atom is centrally located bound to the four nitrogens and to imidazole groups of globin Combination of hemoglobin with oxygen probably involves a displacement of one imidazole group in each ferroprotoporphyrin moiety Different hemoglobins among different vertebrates differ in the amino acid structure of the respective globins

Synthesis of the protoporphyrin of hemoglobin *require only two precursors glycine and acetate* The glycine supplies all of the nitrogen and eight of the 36 carbons The utilization of acetate involves the intermediate formation of a succinyl derivati e arising from the decarboxylation of α keto glutaric acid a component of the citric acid cycle with which the synthesis is closely linked The mechanism for the incorporation of iron is probably an enzyme reaction The essentiality of copper to iron utilization is *well* established

Metabolic breakdown of hemoglobin released on disintegration of the erythrocytes involves oxidative cleavage of the porphin ring at a methene bridge to form linear pyrroles the bile pigments Very little of the iron of heme is excreted most of it being used again in hemoglobin formation or being stored as ferritin Biliverdin a green pigment is first formed and is the main pigment in the bile of some animals but in the human bilirubin (red) is the main pigment The bile pigments are removed from the blood by the liver and are secreted into the intestinal tract in the bile where they undergo further chemical changes Some of the intermediates in these reactions are reab orbed and either returned to the liver or excreted in the urine to form its pigment urochrome *See* BILIRUBIN LIVER

Iron metabolism Iron metabolism relates to iron liberated from functional combinations (for example the heme proteins) in the tissues and that ab orbed from the inte tinal tract The efficiency of iron ab orption is not rated highly however it is impos ible to measure it accurately becau e of the bilateral exchange f iron between blood and the inte tinal lumen Whatever its origin iron is transported in combination with a pla ma globulin (tran ferrin) in the ferric state to the li er spleen or bone marrow where it is relea ed a ferrous iron to unite with a protein apoferritin in the pre ence of oxygen to form ferritin Ferritin contains tightly bound micelles of a ferric hydroxide ha ing the approximate composition [$Fe(OOH)$ $(FeOPO_3H_2)$] its iron content is ariable and may reach values as high as 23% The iron released from transferrin may be incorporated into protoporphyrin to form heme and into the prosthetic groups of various enzymes as an iron porphyrin complex Hemosiderin another torage form of iron combined with protein is found in the ti ues in increasing amounts as the ti sue iron increases beyond the normal physiological levels

The excretion of iron in the urine is normally inconsiderable Its excretion from the skin is continuous and may be important in the daily iron economy of the body Iron released from transferrin in the blood of the subcutaneous capillary bed combines with the proteins in the dermis and is carried slowly to the surface of the kin as the cell of the epidermis desquamate The replacement of the epidermal layers in man is a slow process. *See* BLOOD HEMOGLOBIN [H H ML]

Biblio raphy J S Fruton and S Simmond *General Biochemistry* 2d ed 1958 National Research Council *Conference on Hemoglobin* NAS NRC Publ 557 1958

Iron silicon alloy

A soft (ea ily magnetized) magnetic material Iron silicon alloys are u ed principally as the magnetic core materials in power transformers The yearly product is valued in the hundreds of millions of dollars

Although silicon contents up to 6% have been employed the material most used now contain about 3% silicon The highest quality is obtained by a combination of (1) purification e pecially with respect to nonmetallic impurities such as carbon oxygen and sulfur and (2) control of the processes of rolling and annealing so that the crystallites composing the sheet are aligned with a favorable crystal axis parallel to the *length of* the sheet For a list of properties *see* MAGNETIC MATERIALS [R M BO]

Ironwood

Any of at least ten kinds of tree in the United States which are commonly known as ironwood Because of uncertainty as to just what tree i indicated the name ironwood has been aband ned in the latest check list of the native and naturalized trees of the United State Probably the be t kn wn of the ten is the hornl eam *Carpinus caroliniana* Some of the others are *Ostrya virginiana* ea tern hophornbeam *Bum lia lycioides* l uckthorn bumelia *B tenax* tough bumelia *Cliftonia monophylla* buckwheat tree and *Cyrilla racemiflora* swamp cyrilla or swamp ir nwood All of the e pecies except *Ostrya* are re tricted to the outhea tern United State Other commonly called ironwood are *Euge ia onf* a redl erry eugenia of s uthern Florida and the Florida key *Ex th a paniculata*, butterb ugh of outhern Florida and *Ost ya knoultoni* Kn wlt n l ophornl e m of south ast ern United State Leadwo d *Krugiodendron ferreum* a native of southe n Fl ida ha the high t

pec fi grav ty f ll woods native to the United States and l o kn wn s bl ck ironwood *See* FOREST A D FORESTRY TREE [A N C]

Irradiation isotopic

The bjection f a mate ial to adi t n fr m rad t e sot p (r di t p s) fo the ape t t d other purp e (s e RADIOI OTOPE) Al th gh only rr di t n b ad cti e t pe t treat d in th rt le m ny th r f rm of rad a t n r ed for i r dati n F mpl se ULTRAVIOLET R DIATION (BIOLOGY)

Th re e tw type of t pic ir ad t on In th fi t the ur f rad t on is pl ed n a cap le In th ec nd th rad o t p i d sp r ed n th m te al t be i rad ted Enc p l ted rad a t on n are ed t teril ze f d t ff and b l gi al t pr d changes i pla ti and ther mat r al nd t a d n m d c l th apy Ir ad t on w th di p r ed i otopes la g ly on fi ed t ertai proc du es f m die l th r py n wh h a h rti l ed t pe adm t ed t a patient

Th di t fr m ad et sot pe produ es esse t all th ame ffe t a th rad at on from h gh lt g p rt le I r t r th the h i of a ad o sot p o high ltage ma h n de pe ds prime ily on n en en e and ost A rad o- i sot pe ad t ure d not r quire the ex t e and ompl m hi ry neces ry f a h gh lta rad t ure Rad oi ot p ad a ti h wev a n t be turned n and ff and nsequently req lab r t h eld ng for h lth p ot ct p irp es

At th p e nt t m balt 60 s by f r the m t omm nly u ed ad i t pe f r en ap lated d t n ou c lth h m 13 offe s on de bl p m e p ima ly bec e it i an bu d nt fi n p od t C t m lll a l bl n l rg qu t t s t th p oces ng of f l leme ts f m nucl a t (NL E R FUELS REP OCESS-ING) I deed th ppl n of e um 137 to l t n m l me f th pr blems f d s po g l di t e w tes f om the pe t n f nu le a t

I d e-131 d g ld 198 w d ly d in the di p l t h q A h rti l ed ad t pe dm n t d h bly p r fie l f rm n lly r nt s ly n th a f od e-131 i jected ll dsl f rm di e tl nt a tum m th a of g ld 198 Th pec fi d t g l nt al th apy w th d 131 th t the thyr d gl d nt at th l m nt iod n Co eq tl e t f m f th r d d de a d e ma b t t d b the dm n t at n of la g amount f th sot pe S R DIATION B OLOGY RADIO SC TOPE (BIOL G) [C L B]

Irregularia

Th n m g en by G C e in 1817 t a as m ll g fechi d wh h the nu nd p pro t l t d tl p al t m th mb la al pl tes remain imple the primary radi les are follow and th r g d t t l ow mo e or les bilateral symmet y J D rl am and R Mel ille (19 7) ha e hown that the pyga ter d I regularia tem fr m Late T m e pedi d wherea the other I reg i lar a ev dently aro from Early Jura ic Echino cea The Irreg ilaria re tl er f re an artificial a mbl ge of milar b it unrelated f rm and the name c n ha e n taxonomi val dity S e DIADE MATACEA ECHINOIDEA PYGA TEROIDA REGI LARIA [H B F]

Irrigation of crops

The artifi i l appl c t n f wat r to the soil to produce plant growth Ir igati n in some form has been pract ced inc b f re the dawn of written h tory In the Un ted State about 30 000 000 acre f crops i und r irrigati n

Use of water by plants All gr wing plant i se water c ntinuou ly Tl rat f u e ar e h we er with th ag and kind f cr p grown and th tem p atur and other atm ph r c c nditi n Growth of crops und r irrig ti n i t m lated l y ptimum mo tu c ndition d retarded by es e r deficient m t f water

Co d tions i flu nc ng th amo nt of water i ed by plant incl de i ch fa tors as cl mat a ailable wat r supply so l truct e t p g aphy and cul t ral pr ct ces M i h ir gat n wate i l t l y evapo t n f om l a d water s rface or i t an p red by plant These proce es in mb na t on re called c n umpt e or evapotr n y i a t

The term i rigat n equi m nt me n the am u t f wat r e ded to grow a crop exclu ive of nat ral rai fall Incl ded in th requirem t i wat r ed n t an p ration by plant evapora t on f om the soil and water urfac deep perco-lati n below th root z n nd ther wa te which ann t be econom cally a ided An rrigation r q ir me t f 18 i w uld indic te ufficie t water to c e te th c p are i th t d pth

Water requirement The qu ntity f water re- g dle of it our e equ ed to grow a c op unde normal fi ld o d tions i called the w ter req r ment It i lud ir igat on w t and natu al r nf ll

C ops ha e a p ak per d of wate u e dur ng the g w ☐ se on Irrigati n s t ms must be pl n ed to me t the e pe ods of th water supply

Table 1 Cons mption of w t by various rops

Crop	Co mpt							
	Ap l	M y	J	J ly	A gu t	Sep-tem be	Oc to-be	Se so t
Alf lf	3 3	6 7	5 4	7 8	4	5 6	4 4	3 4
Beet		1 9	3 3	5 3	6 9	5 8	1 1	1 3
Co n	1 1	2 0	4 1	5 8	8 6	6 7	7	31 0
P hes	1 0	3 4	6 7	8 4	6 4	3 1	1 1	30 1
P tatoes			0 7	3 4	5 8	4 4		14 3

is limited either in total quantity or rate of delivery The consumptive use of water by crops has been determined by soil moisture studies or computed by well established statistical methods for many parts of the country Table 1 shows how this varies by months during the growing season The data presented in this table are for various locations and for different years and cannot be applied specifically

Plant–soil water relationships Soil of root zone depth is a storage reservoir for water used to sustain plant growth How often this reservoir must be refilled by irrigation is determined by the storage capacity of the soil depth of the root zone and water used by the crop Table 2 shows approximate amounts of water held by soils of various textures and available for plant use See Table 2

Table 2 Amount of water in soil available to plants

Soil texture	Water capacity in./ft of depth
Coarse sandy [illegible]	½–1
Sandy loam	1½ 1¾
Silt loam	[illegible]
Heavy clay	1 [illegible] or more

Soil conditions position of water table and other factors exert strong influences on root zone depth Table 3 shows approximate root zone depths in well drained uniform soil

Table 3 Approximate root zone depths for various crops

Crop	Root zone depth ft	Crop	Root zone depth ft
Alfalfa	6–10	[illegible]	3
Corn	5–6	[illegible]	1–
Cotton	4–6	Trees	5 10

Quality of irrigation water The quality of irrigation water is determined by total concentration of soluble mineral salts sodium bicarbonate and such other substances as may be toxic to plants

Growth of plants is affected by soluble salts since they restrict their ability to absorb water from the soil When sodium salts are adsorbed by soil unfavorable conditions develop which restrict the entrance of water into plants prevent plant emergence from the soil and make cultural practices difficult

Accumulated soluble salts can be removed from the soil by leaching with irrigation water which moves them below the crop root zone or into drains Adverse sodium conditions are alleviated by the use of gypsum barnyard manure and leaching

Methods of irrigation Water is applied to crops by surface furrows by sprinkling or by [illegible] irrigation method Surface irrigation with furrows is a common means of applying water to row crops The flow carried in furrows between the rows of plants percolates into and replenishes the soil reservoir However on slopes water carried in furrows may result in soil erosion The safe furrow stream may be approximately computed by the formula $Q = 10/S$ in which Q is the [illegible] furrow stream in gallons per minute and S is the slope of the furrow in percentage Maximum length of furrow depends on the size of the furrow stream and the rate at which water is absorbed by the soil Flow control to furrows is accomplished by [illegible] tubes spiles or gated surface pipe (Fig 1)

Corrugations are small closely spaced furrows used in the irrigation of close growing crops They are often employed on soils which crust badly when flooded

Flood irrigation is a method of surface application which may be carried out with border strips basins and contour or bench borders or by flooding from contour ditches

Border strip irrigation is accomplished by advancing a sheet of water down a long narrow area between low ridges or borders the moisture enters the soil as the sheet advances The strip between borders must be well leveled and the grade must be uniform to prevent ponding The ridges are usually low and rounded so that crops can be grown and harvested on them This method is well adapted to close growing crops and pasture but it is also used for row crops Hay and grain can be irrigated on slopes up to 3% and well established pastures up to 6% Slopes below 1% are less liable to erosion damage and the uniformity of application is usually better than on steeper slopes Border strip irrigation when well designed and operated is economical of both labor and water

Basin irrigation is adapted to flat lands It is done by flooding a diked area to a predetermined depth and allowing water to enter the soil uniformly through the root zone It is used for all types of crops including orchards It is also economical of labor and water

Contour or bench border irrigation is used on uniform gentle slopes with moderately deep soil Border strips are placed across the slope on suitable grades The width of each strip should remain

Fig 1 Irrigation of [illegible] (beets) by means of siphon tubes to control [illegible] to each f[illegible]

F'g 2 f g t of w p by m f l g p kl s. T p g phy t o thi F ld t p m t th e f urf m th d

th me th o gh ut t l ngth d b m d n mult pl of the u ual w er p m ch n ry The t g t proce th ame a fo b d tr p r bas n irrig t d pend g n wl th r th t p l p s l l

Flo d g f m nt d t h s t a mmon irri gat n m thod f r cl e g w g crop and pa t re fa d ith un top g phy wh h s d ffi ult t h p f th r m an f w te appl t n F eld d t h r l ly sp eed l ng the ont ur l th l d W t r t d st d f m th m t flow r the nt tre t ge pa ea

Sp nkler gat n d ne by means f p pe f e th t d t w te fr m a *pump g pl* nt to late al l e l g wh ch e l ing p kler he d a e sp ed t app p ate interv ls Lat al l nes moved f om t m t t m a m t e r q re t f th r p r met O e typ f p nkler *s p rlo at d* p pe a me n of w ter ppl a n p rti ul l o ch rd (F g 2)

Ad t g s of sp kl r gatt n a e les h e of l ros n n t ep slop s iform ppl at n n m t so l typ ntr l f wate meet c p d m nds, d gat n with t l nd hap

Some d d a tage f t kli g high t l tme t nd h gh lab r a d p ratt g o t d s t n l pr nkl p tt rn by w d nd wa teful evapc ati n r t t h t d y cl m tes In some e n w sp kle y t m de ig a d b tt r m th d of m g p p h gr tly ed ed l ho d perat g co t

Irrigat on in arid and humid areas Th e ge l g ted r p till e a g n both rid nd h m d reg I d eg n the l mit ng f tor m ften l ck f w ter not f la l ar a to be irr gated Howe er irrig tion pr gramming s f ten ea t r wh n the farmer does n t depen l on n tural ra nfall f r cr p g owth Good y ll are obt ned by maint t ng high il f rt l ty and good so l t lth and by u ing g d r p v riette

There s little difference in the princ ple of cr p prod ict on under irrigat on in hum d regi ns and in arid one The programming of water applica t on i m re diffi ilt n hum l ar a h wev r be cau e natur l precipitati n ca n t be pred ted ac curat ly Climat c nditi n u ually m ke th spr nkler method of irrigati n m re prof tal le in reg on of h gh a rage annual rainfall Se AGRI CULTURAL MACHINERY AGRICULTURAL OIL AND CROP PRACTICES PLANT WATER RELATIONS OF TERRACING (AGRICULTURAL)

[I D W]

B bl ography O W Is ael en *Irrigat o Prin i pl s a d Pr ct c s* 2d ed 19 0 A St ff rud (ed) *W t r* USDA Yearbook Agr 1955

Isanomal temperatures

At t mper tures r th re su h as anil o a tem pe t re that h w equal departures fr m m ta dard Th s t ndard u ually i th l ng t rm a e age tempe at re f r ach pla e but may be the a ge f r an ent re a ea r the ag f r th plac s lat tude

Severity of a umm r he t wa e can be hown by a m p of t mper ture anomal es—differ nces f th average tempe at res f a ingle week m nth r se on fr m the long t rm a erages f r that pe *ri d Pla es with the* me d partures o an malies a e j ed by a mal l nes

Fr m l ng term a a ges f monthly r easonal temp at re t many pl es n the w rld th a er ag temp r ture f r each lat tud nal band can be c mputed D ffer ce b tw n these l t t d nal av e ag and tho at ndi d l p nts can l m a t mp rat re a maly map to how the effects f o tine tal ty *S* AIR TEMPERATURE CONTINEN TALITY WEATHER AND CLIMATE [A C]

Isentropic flow

The fl w f fl id s i ntr pic when it entr py id tic l ll poi t in the fl w l entr p fl w n be app ched f r fluid flowing ther in duct r v the t ide s face of a body Be ca e the entr py f the flu d i a thermodyn mic pr perty mil r t th enthalpy or energy f a fl d th al e f th e t opy is fixed by th t te f th fl d For a pu e ub t n e in the b nc f gra ty pilla ity l ctr c ty and magneti m t py s a f cti n f two indep nd nt p p t f r ex mpl th pre su e and t mpe atu e f r ngl h s flu d (THERMODY AMIC PR NCI PLES)

O l the mplest xamples of ntr pic fl w f a fl d thr gh a nozzle where the flu d i ac ele ted to h gher loc ty by pre r g ad t Th fl w elo ly ppr x mat d by th

is limited either in total quantity or rate of delivery The consumptive use of water by crops has been determined by soil moisture studies or computed by well established statistical methods for many parts of the country Table 1 shows how this varies by months during the growing season The data presented in this table are for various locations and for different years and cannot be applied specifically

Plant–soil water relationships Soil of root zone depth is a storage reservoir for water used to sustain plant growth How often this reservoir must be refilled by irrigation is determined by the storage capacity of the soil depth of the root zone and water used by the crop Table 2 shows approximate amounts of water held by soils of various textures and available for plant use See Table 2

Table 2 Amount of water in soil available to plants

So l te tur	W t p c ty /ft f l ptl
C ly l	½–¾
S ndy lo m	1¼ 1½
S lt l m	1¾ – ½
H y l y	1 – r m

Soil conditions position of water table and other factors exert strong influences on root zone depth Table 3 shows approximate root zone depths in well drained uniform soil

Table 3 Approximate root zone depths for various crops

Crop	R t e d pth ft	Crop	Root d pth ft
Alfalfa	6–10	Potatoes	3
Corn	5–6	C es	1
Cotton	4–6	Trees	10

Quality of irrigation water The quality of irrigation water is determined by total concentration of soluble mineral salts sodium bicarbonate and such other substances as may be toxic to plants

Growth of plants *is affected by soluble salts* since they restrict their ability to absorb water from the soil When sodium salts are adsorbed by soil unfavorable conditions develop which restrict the entrance of water into plants prevent plant emergence from the soil and make cultural practices difficult

Accumulated soluble salts can be removed from the soil by leaching with irrigation water which moves them below the crop root zone or into drain Adverse *sodium conditions* are alleviated by the use of gypsum barnyard manure and leaching

Methods of irrigation Water is applied to crop by surface furrows by sprinkling or by subirrigation methods Surface irrigation with furrows is a common means of applying water to row crop The flow carried in furrows between the rows of plants percolates into and replenishes the soil reservoir However on slopes water carried in furrows may result in soil erosion The safe furrow stream may be approximately computed by the formula $Q = 10/S$ in which Q is the safe furrow *stream in gallons per minute and S is the slope of* the furrow in percentage Maximum length of furrow depends on the size of the furrow stream and the rate at which water is absorbed by the soil Flow control to furrows is accomplished by siphon tubes spiles or gated surface pipe (Fig 1)

Corrugations are small closely spaced furrows used in the irrigation of close growing crops They are often employed on soils which crust badly when flooded

Flood irrigation is a method of surface application which may be carried out with border strips basins and contour or bench borders or by flooding from contour ditches

Border strip irrigation is accomplished by advancing a sheet of water down a long narrow area between low ridges or borders the moisture enters the soil as the sheet advances The strip between borders must be well leveled and the grade must be uniform to prevent ponding The ridges are usually low and rounded so that crops can be grown and harvested on them This method is well adapted to close growing crops and pasture but it is also used for row crops Hay and grain can be irrigated on slopes up to 3% and well established pastures up to 6% Slopes below 1% are less liable to erosion damage and the uniformity of application is usually better than on steeper slopes Border strip irrigation when well designed and operated is economical of both labor and water

Basin irrigation is adapted to flat land *It is* done by flooding a diked area to a predetermined depth and allowing water to enter the soil uniformly through the root zone It is used for all types of crops including orchards It is also economical of labor and water

Contour or bench border irrigation is used on uniform gentle slopes with moderately deep soils Border strips are placed across the slope on suitable grades The width of each strip should remain

Fig 1 Irrigation of row crop (beets) by means of siphon tubes to control the flow to each furrow

Fig 2 Irrg ti f w er p by m o of vol g spr klers. Topog phy is too this fi ld t per it th se of urf m thods.

the sam th gh t t le gth and be made n m ltiples of the u l w-er p ma hinery The irrg ti proc s i th ame a f border trip h na irrigat n, d p d g on whether th t p l pes r s lev l

Flood g f m nt u d t hes i common rr g tion method f cl e-gr wi g crop and pa t re land with es n topography wh h is d ff lt t hap f oth m n f w te ppl cati F ld d t hes losely p ed l ng th nt u of the land. W ter d erted f om them t fl w er th interve ing crop a a.

Spri kler irrig t d by me n of p pe lines th t condu t wat from a p mping plant t lat al lines l g which rev lvi g prinkl h ad a sp ed t appr pri t t tervals Lat r l lines are moved f m t m t me as m ture eq e ments of th er p e m t. O e type of spri kl uses pe f rated p p m f w t ppl tion, p rti ul ly in ha d (F g 2)

Ad nt es of prinkler rr g tion a e less han f ao l ros on teep l pes, un form ppli t on m t l types l f water to meet p d m d d irr gat n with ut l d shap g

Som d d ant ges f p inkli g h gh it l m estm t d high labo d pe t ng ts, d s tortion f sp kle p tt rn by wi d and wasteful evapo ti ates b t dry lim tes I me e new p inkl y t m des gn d bette m thod of moving p p h g e tly reduced l bo d per t ng ost

Irrigation in arid and humid areas The e ge f irrig ted cr ps st ll ncr both rid d h mid r gi l rid th limiti g fa tor i ft n la k of water not f land are t be irrigated H wever irr ig ti n pr gramming i f ten e ier wh n the farmer does n t depend n natural rai f ll for crop growth Good y eld are obtai ed by m taining h gh s il fertil ty and good soil tilth nd by ng good cr p vari ties

Ther i littl differ n in the principles f cr p production der rrigat n in hum d r gi n and in arid es The progr mmi g of water applica ti n i m re d ffi ult in h mid a a h wever be au e nat ral p ecip tati n ca n t be pred ted ac curat ly Cl m tic d tion u ially mak the pri kl r method f irrig ti n m re pr fitabl in eg n of high a er ge ann al rainfall Se AGRI CULTURAL MACHI ERY AGRICULTURAL OIL AND CROP PRACTICES PLANT WATER RELATIONS OF TERRACING (AGRICULTURAL)

[I D W]

Bibl g phy O W I rael en *Irrig t n Pri ple a d P act c s* 2d ed., 1950 A St ff rud (ed) *W t r* USDA Y arbook Agr 1955

Isanomal temperatures

Air temper t res or oth m uch s soil or se t m p rat res that h w eq al d partu es fr m some st d rd Th t ndard u lly i the l ng term a erage temperat re for e h pla e l t m y be th a rag f n ent re rea or the rage f r th pla l t tude

Sev ty of a mm r he t wa e c n be sh wn l y a m p of tempe at re a omalies—d fferen es f the er g temperatu es f r ngle week m th o se son f m th l ng t rm ave ges f r that pe r od Il es with the same d partures n mal es are j ined b ısa mal l es

F m lo g term erages of m nthly aso l t mpe t r t ma y places i the w rld the er ag temperatu f r e h latitudi l h d c n be c mputed D ffere es between these lat t d nal a rages a d those t nd id l po nt can f rm a tempe t re a m ly map to show the ffect of continentality S AIR TEMPERATURE CO TI EN TALITY WEATHER AND CLIMATE. [A C.]

Isentropic flow

The fl w of a fl d entr pic when t ent py is id t al at ll po ts i the fl w Isentrop c flow n be app a hed f flu d fl wing th r n a d t er th nts d f c f a body B ca th ent py f the fl d i a thermodynami pr p rty s m la t the nth lpy o e gy of fl d the v l f the nt opy s fixed by th stat f the fl d F p b t nce n the absen e of g ty ap ll r ty lect ty a d magnet m en tr py fu t n of tw ndepe d nt p pert es f e ampl th p e u nd t mpe t f r a gl phase flu d (se THERMODY AMIC PRI CI PLES)

O e f th mplest mples f tr p fl w of a fl d th ugh zzle wh th fl d i a celer ted t higher loc ty by a p es e gr d t Thi fl w closely app x m ted b the as-

is limited either in total quantity or rate of delivery The consumptive use of water by crops has been determined by soil moi ture studies or computed by well established tatistical methods for many parts of the country *Table 1 shows how this* varies by months during the growing eason The data pre ented in this table are for various locations and for different years and cannot be applied specifically

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So l te ture	W t cap ty in /ft f d pth
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S dy lo m	1½ 1½
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H a y l y	1½ m re

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Table 3 Appro mate root zone depths for various c ops

C op	Root zo d pth ft	Crop	Root o e d pth ft
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Contour or bench border irrigation is u ed on uniform gentle slopes with moderately deep soil *Border trips are placed acro s the slope* on suitable grades The width of each strip hould remain

Fg 1 I gat on of ow c op (be t) by m a of s ph n t b s to co t ol the flow t e ch fu w

g 2 I rgat f w p by m f l g k ll rs. T p graphy t th fi ld to ermit th use of rf m thod

h same th gho t t le gth a d be mad m h ltiples of th u al row-c p mach nery Th rrigatu p oces th me s f bo de t p ba i rigat d p d g o whether the tr p l pes ri ler l

Flood ng f m t d t he i a e mm t i r m th d f l e g wi g er p and p tu l d with ev t pog aphy wh h i difficult t th pe f oth me f wate appl cat n F ld dit he e cl ly p ed al g the o t ur f th land W te i d ted from them t fl w ov r th i terve i g er p a.

Spri kler irr g t o t do e by m ans f p p lines th t co d ct w ter fr m a p mping pl nt t lat ral lines l ng wh ch re l ing p i kler head a pa ed t approp te i terval Late l l ne e moved f m t me to t me as m t qui ments f th c p a m t On typ f sp kl uses pe f r ted p p a mean f w te ppl ti n rticul ly rcha d (F g 2)

Ad t g s of p i kl g t o are le s han f so l r n n t p l pes unif rm appli ti n m t s l types c trol f water t meet p d m d d rrig t w th t l nd sh p ng

Som d sad tage f sp nkl n h gh ti l n estm t and h gh labo d op t g o ts d t rtion of pri kler p tt rn by w d nd w t f l evapo t rat r h t dry l m t I m ca.e new sp nkl y tem des gn d bett r meth d f mov g p p h e gr atly ed ed l bo a d p t ing co t

Irrigat on in arid and humid areas Th e ge f rrigated s t ll n ea g n both rid d hum d egi ns. I a d gi n th l m ti g f to i often l ck of water n t f lan l a ea t l ir gat d Howe er irrigati n pr grammi g i of te ea ier when the farmer does n t d pend n natural r i fall for rop gr wtl Cood yield are obtained l y m intai i g high s il fert lity and good oil tilth and l y u ing good i p varietie

There is l ttle diffe en e in th p inciple f cr p production under irrigat n in l umid reg n and in arid ones. The pr gramm ng f water appli a ti n s m re diffe lt in h m d are l owever l e- e u natural precip tati n c nn t l e predi t d s cur t ly Climat c c nditi n i ally m k th prinkler method of irr gati n m r prof tal le in regio s of high a rage nnual ra nf ll Se AGRI CULTURAL MACHI ERY AGRICULTURAL OIL AND CROP PRACTICES LANT WATER RELATIONS OF TERRACING (AGRICULTURAL)

[I D W]

Bibliogr phy O W I raelse *Irr gat n Pri ci ple d P act ces* 2d ed 19 0 A Steff r d (ed) *Wate* USDA Yearbo k Agr 1955

Isanomal temperatures

Air tempe atu r ther h a so l or ea tem p rat res that h w equal departu s f om m t d d Thi tandard u ally i the long t rm a erag tempe at e f r ea h place but may be the a age f r an ent re re or the a erag f th pl s l tit de

Se rity of mm r h at w e an be h wn by a map of tempe t re a mal es—diff r nces f the a er ge t mp atu es f r a gle w k m th o se n from th l ng term averages f r that pe- riod Pl es with the ame depa t res r an m lies re j ned by i an mal l es

Fr m lo g te m a rages f m nthly s eason l temper t r at m y places th w rld th er ag temperature f e h lat t d nal l nd a be omputed D ff en e between th e latitudin l a ages nd th e at de id al po nts an f rm a t mpe tu a m ly map t how the effect f nt tal ty *See* AIR TEMPERATURE CONTINEN TALITY WEATHER AND CLIMATE [A C.]

Isentropic flow

The fl w f flu d s entrop c wh n tr py i de tic l t all po t in the flow I ent opic fl w ca b appr ched f r fluid flow ng th r a d ct o ve the ut d urf ce of a body Be a e the nt py of th fl d th rmodynami p p rty m lar to the e thalpy energy of a fl d the l of the tr py fixed by th tate f th flu d F a p a b t e in the b *nce of* gr ty capill rity lect ty nd mag ti m e t py i a fu ct n f two d pe d t pr p ti f r x mple the p nd t mp rat for a gl ph se fl id (se THERMODY AMIC PRI CI PLES)

O e f the mplest e mpl f i trop c fl w f a fl d i th gh nozzle wh ei the flu d i ler ted t highe loc ty by a pr e gr di t Th s fl w cl ely ppr x mated by the as-

sumptions that it is one dimensional adiabatic and frictionless (reversible)

In an actual nozzle the fluid flow is not completely isentropic because (1) the fluid shear stress at the walls is not zero thereby introducing some friction (2) a ignificant rate of heat tran fer can occur between fluid and walls as in a rocket nozzle (3) a significant rate of mass transfer or diffu ion may occur normal to the tream lines thus producing local changes of entropy in the real flow and (4) chemical reactions can occur in the flow and thus cau e local change of entropy

Although the real flow in a nozzle is only approximated by an i entropic flow the latter flow can be computed quickly in compari on with the long and tedious calculations required for the real flow Hence i entropic flow is often used as a basis of compari on of the real flow with the ideal flow Thus the figure of merit for flow in a nozzle is defined by

Nozzle efficiency = V / V

where V is the actual measured velocity i suing from the nozzle and V is a hypothetical velocity for i entropic flow of the same fluid from the ame initial state to the same exit pre ure as the real flow

The concept of i entropic flow is applied u efully to many applications for fluid flow inside ducts and out ide of variou ly haped bodie I entropic flow is also used for predicting such flows a those of perfect ga es real gases di sociating and chemically reacting system liquid two phase single and multicomponent systems and pla ma

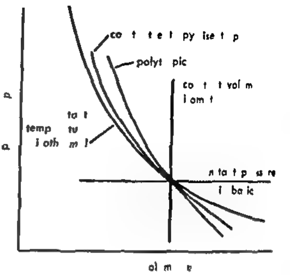
I entropic fluid flow can be obtained in irreversible proce ses by electing a proce s in which the local entropy could increa e and then providing for sufficient heat transfer to maintain the entropy constant at all points *See* FLUID FLOW PRINCIPLES GAS DYNAMICS [J KA S I F]

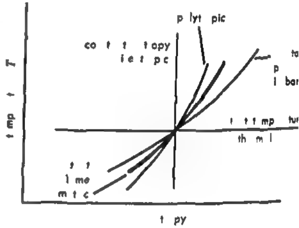
Bibliography J H Keenan *Thermodynamics* 1941 J H Keenan and J Kaye *Gas Tables* 1948

Isentropic process

A frictionle s pi ton moving in an insulated cylinder may be u ed to depict this thermodynamic proce s Sy tems which are thermally insulated from their surrounding undergo proce es without benefit of any heat transfer and uch proce e are referred to a adiabatic Becau e the i entropic proce s is conducted without any di ipati e effect and becau e it receives no transferred heat it is sometimes called the re ersible adiabatic proce s

Work done during an i entropic expansi n is produced at the expen e of the am unt of internal energy tored in the nonflow or clo ed sy tem Thu the u eful expan ion of a gas i accomp nied by a marked decrea e in temperature tangibly demon strating the decrea e of internal energy st red in the sy tem The path is indicated on the diagram *See* THERMODYNAMIC PROCESSES





Isent opic p ocess compo d to other thermodynam p oce ses

For gases the isentropic process can be e pres ed as

$$P_1V_1^{k} = P_2V_2^{k} = \text{constant}$$

where P is pressure in pounds per square foot ab lute V is specific volume in cul ic feet per p und and k is the ratio between the specific heat at constant pre sure and the spe ific heat at con tan volume for the gi en gas It can be clo ely approx mated by the alues of 1 67 for monat mic ga and 1 40 f r diatomic ga e [J B

Isentropic surfaces

Surfaces along which the entropy and potentia temperature of air are constant P tential tempera ture in meteorological u age i defined by th relation hip

$$\theta = T\left(\frac{1000}{P}\right)^{\frac{R}{c_p}}$$

in whi h T is the air temperature P i atmo pheri pre ure expre ed in millil ar c i the specific h at of air at c n tant p e anl c i the spe cific heat at con tant volum Since th p tential temperature f an air parcel d not change if the proce es acting o it are adial tic (n ex hange

(h t betwee the parcel and ts en ironm nt) a fa e of con tant pote t l temper tu e is al o a urface of consta t entropy Th lope of isentropic urf es in the atm pher is of th rder of 1/100 a 1/1000. A d ntag of rep e enting meteo o- gical d t on n i ent opic s faces s that here u ally l ttle a r motion thr ugh such sur tes, s nc th rmodynamic proces es in the atmos- her are approx mately adiab tic [F S]

Island faunas and floras

I' ds pro id sh g ecol g cal bounda ies in con ra t to cont nts, where the boundar es of an are inh b ted by spec es an be e tabl hed ly approximat l B th fa n s nd flora of land ge erally ha e ch racter of their wn becau e of the peculi r co d t n unde which they dev l p Th refo i e to es f the spe ies in i la d a eas ar of m r meaning t the ol gi t

Developmental conditions Development f populati n i land m lve a con d tio f ch f t s lat n a d disjunct on attenua ti f the fl a a d fauna a d co t n ntal ers s oce ic islands

I olatio a d d sjunct on of the p pulat ns A species may be d tr buted eve al la d and co tinents. However it is u u lly s fe t a me th t an la d populat on s b ed g unit without mu h ont t w th the rest f the speci that s, i is d jun t. The s l ti n of such b eeding p pula ti m y l ad t evol t o ry ch nges r sult ng in subspec es p es p cul r r endem t the i land

Atte uatio f fl ras and fa nas Isl nds are gener lly poo e n plant and n mal species th n comp rabl c tine tal a eas E pec ally on oc anic i lands the flora and fa a ha e bee lected by th r b lity to the ce n S n e elati ly f w t rrestrial g n sms can tr el gr t d t n es overseas al fl r s d f unas ca be regarded I a ti f n s by cont e t l ne

C ntin tal t us c anu isl nd Cont ental isla d ha e been co n cted to nt nt in th r geol gic p t th t the f un s d fl ra can b e plai ed on the b s f m grat n acr l nd bridges. Th pple t sm ll fl h r i land l ke Nant ket nd V e I la d s w ll as t l rger ones n h a th Brit h I les d N w Gu n a H er r geolog d c upport the w that th Azo es Can ry Isla d Micro e ia H wa i nd p h p th Ant lle so n the m ddle of oce The fl as a d f as f s h o e n c i land m t th ef b e pl d a es It of occ to al d p l c the c n and subs qu nt local pr p g t n and e lut on

Endemism O a isla d sp cially h gh u a d w th a variety of alt t d n l l m t zones support many pec e pec l ar or *endemic* t th m In th as of nt e t l la ds d t n t n m t be mad c rding to the s la ds If sep r t n oc urred d ing the Creta eou o e ly T iary the fa a and fl a ha e a mo e oc a chara ter tha if an i la d were separated during the later Plei t ene Th character is exp ed in the per entage f endem c pec es

To determine ndemi m all pecies f animal r pl nts on an i land m y be a igned to the f l low g groups

1. I troduced pecies mmigrant through human ag ncy
2. Nati e p e immigrant through no human agency
   a. Widespr d nati e peci fou d l ewhere s w ll as n th i land
   b. E dem c pecie peculiar to the i land r i l nd grou not fou d el ewh r

The p ent ge and di ti cti enes f en l mi in the nati e fl a and f una ar imp rta t i d ca ti n of the degree f i lat n f an i l nd

Geographic elements I land populat ns, whether di tinct r n t are u ually related t species n nearby c ntinent In ular pec es wh ch ha e relatives the same gene al eg n re aid to be- lo g t the ame geog phic lement fau i t c or fl ri t c el ment. Thu the fl ra f Hawaii com posed f an Indo-Pac fic n Au tral an Am rican a bo eal (North rn) tr pical a Hawa i and n introdu ed el ment

In der to obtai i formati n ab ut the r es f insular fl ra and fau a s nece ry t have kn wl dge of all la d a ea a o nd an i land ocean c rr nt a d p e l ng wi d direct on E en l rd migr ti n r ute h uld be g en pr p r con idera ti

Si e d m c pe es and gener h e r ided n i la ds for a l ng t me the i a i n f the i land by the nc t rs may ha e tak pla e und r en tir ly d ffer nt i cumstance from tho today Is- land may ha e changed n ize clim t r r e ta t n with re pe t to wind d e t on and currents getat and animal l fe o the ne ghbo ing c nti nents als may h b e different. Th mo t dis- t n t e a insula populati n the mo l k ly th t ts immigrat n c rred l ng ag and under d ffer nt c rcum ces The mo t r cent invad rs on most i l nd re t od c d o gan sm su h a rat mic roache Cau a ian m n and many weedy pla t

The relic nature of island populations I lands and i land g o ps re e nd ci e t olut on of e d m c p pul t s al o m ny pecies one w d ly d t b ted h e bee me lim t d to i l nds On the c nt ne ts th r are greater l matic flu tuat ons and m e ompet t on amo g compara t ely la g umbe f spe i s New f rm aris and pr d ap dly i d ng many hab tats On is- land the l m t s m r table nd equ bl th o gh th ges M ny agg ive pecies of c n t nental r g n h ot r a hed land As a result, m t f rm f I f ar *in efuge* on sland as el p b ot pop lat ns

Th i l ds the North Atlant su h as the A e M de a d Can ie ar till egetated by

laurel forests similar to those that disappeared from the Mediterranean as living forms long before the glacial epoch and are now found in its Tertiary fossil bed. The unique mammal life of Tasmania, the dragon trees of Socotra, and the silverswords and tree plantains of Hawaii are other examples of ancient forms of life surviving in the isolation of islands. *See* EVOLUTION, ORGANIC; POPULATION DISPERSAL. [K.L.E.]

Bibliography: S. A. Cain, *Foundations of Plant Geography*, 1944; R. Good, *The Geography of the Flowering Plants*, 2d ed., 1953; D. Lack, *Darwin's Finches*, 1947; E. D. Merrill, *Plant Life of the Pacific World*, 1945; A. R. Wallace, *Island Life*, 1881; E. C. Zimmerman, *Insects of Hawaii*, vol. 1, 1948.

Isoantigen

A serologically active protein or polysaccharide present in some but not all individuals in a particular species. These compounds initiate the formation of antibodies when introduced into other individuals of the species that lack the isoantigen. Like all antigens, they are also active in stimulating antibody production in heterologous species. The ABO, MN, and Rh blood factors in man constitute important examples. Consequently elaborate precautions for typing are required in blood transfusion. Analogous situations exist for the bloods of most other animal species. Isoantigens are also believed responsible for the ultimate failure of tissue grafts between individuals of the same species, except those of the same genetic constitution or those that have been rendered tolerant, a situation of consequence for the surgical procedure of skin grafting.

Isoantigens are to be distinguished from autoantigens, which are antigens active even in the species from which they are derived and in individuals who already possess the antigen. Brain and lens tissue as well as sperm constitute examples. These exceptions to the usual rule of nonantigenicity for self constituents may be more apparent than real, however, since the substances cited are all protected to some degree from contact with the blood and thus normally do not reach the sites of antibody formation except after experimental manipulation. Autoantibodies may also be produced in various disease states, perhaps as a result of modification of normal tissue by the infecting microorganism or by altered host metabolism, for example, the paroxysmal hemoglobinuria observed in syphilis, acquired hemolytic anemia, or some of the manifestation in rheumatic fever. *See* ANTIBODY; ANTIGEN; BLOOD GROUPS; POLYSACCHARIDE; PROTEIN. [H.P.T.]

Isobar (atomic physics)

One of two or more atoms which have a common mass number A but which differ in atomic number Z. Thus, although isobars possess approximately equal mass, they differ in chemical properties; they are atoms of different elements. Isobars whose atomic numbers differ by unity cannot both be stable; one will inevitably decay into the other by β^- emission $(Z \rightarrow Z+1)$, β^+ emission $(Z \rightarrow Z-1)$, or electron capture $(Z \rightarrow Z-1)$. There are many examples of stable isobaric pairs, for instance, Ti^{50} $(Z = 24)$ and Cr^{50} $(Z = 26)$, and four examples of stable isobaric triplets. At most values of A the number of known radioactive isobars exceeds the number of stable ones. *See* ELECTRON CAPTURE; RADIOACTIVITY. [H.E.D.]

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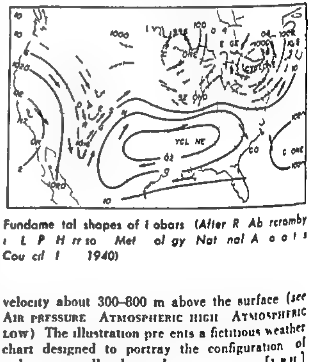


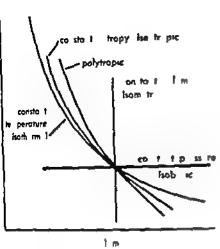
Fundamental shapes of isobars. (After R. Abercromby, in L. P. Harrison, Meteorology, National Aeronautics Council, 1940)

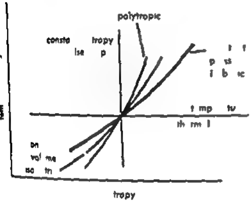
velocity about 300–800 m above the surface (*see* AIR PRESSURE; ATMOSPHERIC HIGH; ATMOSPHERIC LOW). The illustration presents a fictitious weather chart designed to portray the configuration of isobars generally observed. [L.P.H.]

Isobaric process

A frictionless thermodynamic process of a gas in which the heat transfer to or from the gaseous system causes a volume change at constant pressure. Such a process is illustrated by the expansion of gas when it is heated to lift a weight or do other work on its surroundings. Mathematically

$$Q_P = W + U_2 - U_1 = \int_1^2 P\,dV + U_2 - U_1$$
$$= P\int_1^2 dV + U_2 - U_1 = (P_2V_2 + U_2) - (P_1V_1 + U_1)$$





Isobaric oc ss mp ed t th th m dy m proc se

$$Q \quad H - H = m \int_1 C \, dT = m \int^2 T \, ds$$

her Q t th tra f r ed h t at n ta t p es- F is w k P i ab l te p s re H i enthalpy U i te l e gy I i l m m t mas C s p fi h at t c ta t pres nd is t py S THERMODYNAM E PRINCIPLES

[J B]

Isocyanate

On of a gr up f eut l de i at s of p im ry m f rm l R—N=C=O th t are obta ed by acti w th xc ph nd l f by drogen hl d Eq (1) S A Two do bl bond b g a ry r t syst m sef l in the dent fi tio of l h l and ph l u th (RNHCOOR) Eq (2) m e n a Eq (3) lkyl h l d s s l des (C$_6$H NHCOR) Eq (4) d b yl c a ds s m d s (RNHCOR) Eq (5)

$$RNH + COCl \rightarrow RNHCOCl \rightarrow R{-}N{=}C{=}O + HCl \quad (1)$$

$$RNCO + R\,OH \rightarrow RNHCOOR \quad (2)$$

$$RNCO + R\,NH_2(\; R\,R\;NH) \rightarrow RNHCONHR \;(\; r\; RNHCONR\,R\;) \quad (3)$$

$$RX \rightarrow RMgX + C_6H_5NCO \rightarrow C_6H_5N{=}CR(OMgX) \xrightarrow{H_2O} C_6H_5NHCOR \quad (4)$$

$$RNCO + R\,COOH \rightarrow RNHCOOCOR \rightarrow RNHCOR + CO_2 \quad (5)$$

Isocya tes hydr lyze in air to the un table

$$RNCO + H_2O \rightarrow RNHCOOH \rightarrow RNH_2 + CO_2 \quad (6)$$

rbamic acid (RNHCOOH) which revert t the or ginal ami es b y lo f ca bon d xide Eq (6) Unhydr lyzed i ocy nat the react with th amine t gi e a ymmetri l urea RNHCONHR N r mally an impo ta t reacti n nly be u e the nui s nce mu t be a ided co troll d hydr ly i of free i ocy nate group t liberate carbo d xide is the b i f o e type f f med plastic *S* POLYURETHA E RESIN

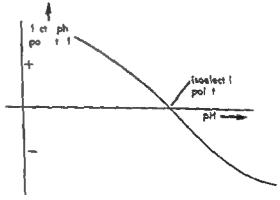
To a oid hydroly m by atm pheric m i ture socyanates a e best k pt in se led glas c nt i er

Repl cement f xygen by ulf r a m isothiocyanates red ces the ctivity c n id ably

[L.B C.]

Isoelectric point

The pH al e of the d sp n med m of a col lo d l u pen n t wh ch the coll id l particle d n t m e n a elect i fi ld th t i the parti les ar el ctr ph r tic lly i ert The iso lectric poi t is fte empl yed t ha a t ize llo dal m te l u h a th prot i However r nge of l es s i ally neces ry m ce the i lectric poi t v r d te tably w th (1) the ize f th par ti les (2) the pur ty and (3) the co ntration of io s p e nt ther than hyd ogen ion



G ph how g th l ct c po t

If the pH l e of an ext n c ol (tab lity at t b t d p im ily to ele t i al ha ge) i djusted tow d th i le t po t coagul ti n w ll occur at n ar th o l ctr c point I t insic sol (ta b l ty tt b ted pr ma ily to ol at) may be ar ri d to th elect c p nt with ut co gulat on but h l will be in a regi n f min mum sta b l ty s that m n mum c n e tr t n f d l t

laurel forests similar to those that disappeared from the Mediterranean as living forms long before the glacial epoch and are now found in its Tertiary fossil bed. The unique mammal life of Tasmania, the dragon trees of Socotra, and the silverswords and tree plantains of Hawaii are other examples of ancient forms of life surviving in the isolation of islands. *See* EVOLUTION, ORGANIC; POPULATION DISPERSAL. [K.L.E.]

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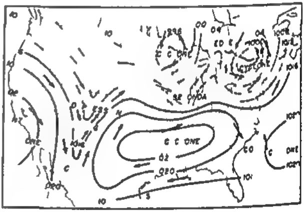

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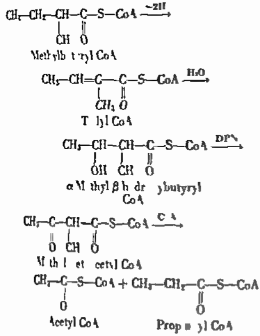


[E A A D]

Isomerism molecular

Th t rm m i m was t od ed by J J Be e li s f d ffe t chem al c mp u d ha ng th ame el m tary e tage c mp sit on that th rel tive p op ns f onst t e t le m t Th p b l ty th t th s me lement ry c mpo t n d te two m b t n es isom de s f m ga stru t e theo y whi h req es ly th t th len e n mbe of e ch l m t (rb 4 yge 2 hyd ogen 1) be f ll t fied Th s the ide tity of ny g en comp und i fu t f the a g m t orde f) k g of th ompo e t l ments

Chain isomerism Am ng th alk e C_nH isomer m res lt f m th p ab l ty of l k g th sam number f rb n tom to pr d e the a straight h i br hed cha s f r mple C H repre ts b t $CH\ CH_2$ $CH\ CH_3$, d ob ta e, CH CH(CH) A the numb f arbon nc the mb r f m m ses C H r p e t CH CH CH_2 $CH\ CH_3$ CH CH CH(CH) a d C(CH) Ch isom r th d ff f m ch th r by virtue f po es ing d ff ent b k let n

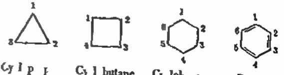
Position isomerism Th p ti f l m t (l m t) th th n c b n nd hyd ge h h tak s the pl ce f on m hyd og s m gr t e t isome st tu Th mb r of su h m d t rm ed by th mb f d ff nt typ f hyd og a gi e hyd a b Thu m m l le of m th n eth d o- pe t e, ll th h d gen t m a qu l nt (m b t t ted some re p bl d all d n t es f form l C_nH Z r d nt l) b t propane, but a d i b tan h ha tw d f f ent type of hyd g and e pabl f p o- vid ng t d ff t m b t tuted d at

C_nH Z (for e mple CH CH CH_2Z and CH_3 CHZCH)

If m re than on hydrog n atom i replac d by toms f one ul tit ent lement m re po it n i omer a e po ibl f e en etha e may pro- ide the e Th principle h wever remains the ame the n mber f d ff rent type f hyd gen i a gi en m no l tit ted alkan determ ne how many i om r e d ub t tuted isomers ar p s- ble Thu C-H ZX (where Z and X may be the same or d ffer nt eleme t) r pres nts CH CHZX nd CH ZCH X a d C H ZX repres ts CH CH CHZX CH CHXCH Z, CH_3CHZCH_2X CH_2- XCH CH Z and CH CZXCH the e nd nd th rd bei g id nti l if Z and X represent the ame eleme t

In un aturated mpound (s mple alke es and alkyne) the n mb r of un que l cati n for the d uble o tr ple bond determ nes the n mber f po tio isomers Thus a f ur-carb alkene (alkyne) i th imple t sy t m f r wh ch po it nal someri m is p ble CH CH $CH{=}CH_2$ nd CH CH C≡CH or CH CH=CHCH and CH_3 C≡CCH

In symm trical ycl c sy tem (cycl alkanes d be ene) all hyd oge a e eq ale t and o a with eth e at le t tw ul t tuents mu t b pr e t f the exi te ce of po ti nal isom r The numbe of h t m s depend on th ze f the ng whe the numb f ub titu nts (fo ex mple Z a d CH) is lim ted to tw Thu there are tw d ub t tuted cycl pr p nes (1 1 a d 1 2) three d ub t tuted cycl but nes and cyclo- pe t ne (1 1 1 a d 1 3-) and f r d si b ti tuted cy lohexan (1 1 1 2 1 3- and 1 4-) The at re of the be n r ng l mits d sub ti tuted be z es to th ee 1,2 (th) 1 3- (m ta) a d 1 4- (pa) Wh r the e are th ee denti al s b t tu nt C_6H Z th ee po t o al i me s are p ble (1,2 3- 1 2 4- a d 1 3 5-) b t f C_6H Z X th e are fi (1 Z- 2 Z 3-X 1 Z- 2 Z 4-X 1 Z- 3-Z 2 X 1 Z- 3-Z 5-X 1 Z- 4-Z- 2 X) A m thod f r d term n g the ab o- lute po t n f h s b t t ents i b n ne de- pe d up n th per me t l p od ct on of o l ome f m a g e d ub t tut d be ze e (Ko ner m th d)



Cy l p p   Cy l butane   Cy loh xan   Benz n

Wh cy l sy tem i n t symm tr l (cy lo- lk e h t cycl c mp d bi d p ly ycl sy tems u h s d l n d naphth l n) th p t hydr rb p e es mo e th n o typ f hyd ge t m d h n e p ti al i mer m i p bl w th but o b t t e r wh eas p ly sub t t t l ad t a g t m lt pl ty of p t nal ome tha ymm t i l y l y t m

ing agent will cau e coagulation Likev i e vi co ity changes often reach a minimum at or near the i oelectric point *See* COLLOID ELECTROPHORESIS ION PERMEABLE MEMBRANE PROTEIN [W O M]

Isoelectronic sequence

A term u ed in pectro copy to de ignate the et of spectra produced by different chemical elements ionized in uch a way that their atoms or ions con tain the ame number of electron The following equence i an example

De ignation of pec trum	CaI	ScII	TiIII	VIV	CrV	MnVI
Emitting atom or ion	Ca	Sc^{+}	Ti^{++}	V^{+++}	Cr^{++++}	Mn^{+++++}
Atomic num ber Z	20	21	22	23	24	25

Since the neutral atom of the e element each con tain Z electron removal of one electron from candium two from titanium and o forth yields a erie of ions all of which have 20 electron Their spectra are therefore qualitatively imilar but the pectral terms (energy level) increa e approxi mately in proportion to the quare of the core charge ju t a they depend on Z in the one-elec tron equence H He Be and o forth (*see* ATOMIC STRUCTURE AND SPECTRA) A a re ult the ucce ive pectra hift progre ively tov ard horter wavelength oon reaching the vacuum ul traviolet region I oelectronic equence are u eful in predicting unknown pectra of ion belonging to a equence in which other pectra are known

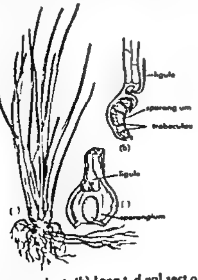
[F A J]

Isoetales

A monotypic order of the plant ul phylum Lycop ida containing only one genu *Isoetes* The e plants are called quillw rts becau e in all 64 pe cies the leave are long and narrow with a poon like ba e pirally arranged upon an underground cormlike tructure *See* STEM (BOTANY) Mo t pe cie are emiaquatic although a few are terrestrial They are confined to the c oler regi n of the world

Morphologi t differ in their opini n regarding the relation hip of the gr up They are like the Selaginellale in having ligule two kind of pore (hetero porou) and in producing tw kind of gametophyte They are different fr m the other Lycop ida in having multiciliate perm in lacking a u pen or (a chain of cell which erve to put the embryo in a favorable po itı n in relati n to it food upply) and in po e ing a econdary meri tem which develop ome econdary ti ue (*see* MERISTEM LATERAL) The pre ence of a pe cial root producing region which devel p new di chotomou (forked) root each year together with their anatomy ugge ts a clo e relation hip with the fo il Lycop ida e pecially the genu *Pleuro meia* The phyl genetic connecti n between *Pleur meia* and *Isoetes* i accepted by many b tani t and for thi rea on the familie Pleur meiaceae and I o etaceae are often included in the I oetales *See* PALEOBOTANY PLEUROMEIALE TRACHEOPHYTA

[P A V]



I oet s (a) E t e pla t (b) Long t d nal sect o f l f bas (c) Face ew of ve tral s face of l f ba e (From A J Eames E W S n a d K S W l Bot y P c ple a d P oblem 5th ed McG aw-H ll 1955)

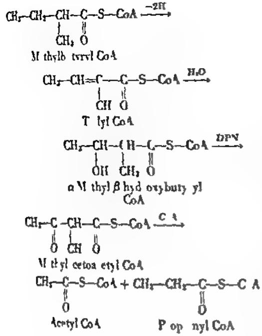
Bibliography *See* LYCOP IDA

Isoleucine

An amino acid c n idered e ential f r normal growth of animal The amino aci l are character ized phy ically by the following (1) the pK or the di ociation con tant of the vari u titratable group (2) the i electric point or pH at which a dipolar ion d e not migrate in an electri fi ld (3) the ptı al r tati n r the r tati n imparted to a beam of plane-p larized light (frequentl the D line of the odium spectrum) pa ing thr ugh 1 decimeter of a lution of 100 gram in 100 ml (4) olubility *See* EQUILIBRIUM IONIC I OELEC TRIC POINT OPTICAL ACTIVITY SPECTROPHOTOMET RIC ANALY I

The bi ynthe i f i leucine ccurs wh n pyru ate and α ketob tyrate react to f rm α-aceto α hydr xybutyrate which underg e rearrangement and red ti n to α β dihydr x β methyl al rate Dehydrati n t the α keto aci l and tran aminati n compl ete the b ynthe i (*see* AMI O ACID) M t r ll f the enzym e nc rned al cat lyz the anal go rea ti n i valine bi ynthe i *See* VALINE

During metabolic degra lati n the fir t t p are l aminati n and oxi lati le arboxyl ti n f rm ing α m thylbutyryl enz m A (α m thylbut ryl C A) Th f ll wing r ene tak pla



[E A AD]

Isomerism molecular

The t m som r m was t d ced by J J Berze- lıu f r diff nt ch mı al omp unds h ng the sa e el me t ry p ce tage mp ıt on th t ı th me relat e p ▪ tı n f c n tıt nt ele m ts The po b l ty that th am el m ntary compo t a den t two r m ubstances som r d rı f m organ t uctu theory whı h eq es only th t the ale ce n mb of e h l m nt (k 4 oxyg hyd g n 1) be f lly t fied Thu the ıde t ty of y g en compou d f nct f the a r g m nt r d f l ka l th mpo t lements

Chain isomerism Am g the alk ne C_nH ısom m results from the p s b l ty f lı k ng the same umbe f c bon t m t p oduce e ther a tra ght ch br ch d h ın f ample C_4H pr sent b tan CH CH_2- CH CH nd ısobuta CH CH(CH) A th mbe f bon n r es th be of so- me ▪ es C H repr nt (H CH CH- CH CH CH_3CH CH(CH) d ((CH) Ch m r the d ffer fr m e h othe by ıru f posses g diff nt ca b n kel to

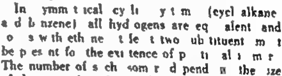
Pos tion isomerism The po ıt n f n l me t ( ) m t) tl r th n a bon d hydr g n wh h take th pl e of ▪ ▪ m hyd e may gı e e t ı me t ctu e Th ▪ mbe f u h somers det m ed by th numb of d ff rent types of h d g g n hyd o b n Th s ın m lec l f m tha e, th ne nd neo- m n bstıtuted m r a ▪ bl and all de- a es of form la C_nH Z a e d nt al) b t prop b t ne d ı but n a h ha e tw d f ferent types f hyd g n nd pabl f p o- d d t s

C_nH Z (f r example CH CH CH_2Z and CH_3 CHZCH)

If m re than one hydr gen ▪ m ı replaced l y atoms of o e tl t tuent element more p ıtı n ısomer are po ıble and e en etl ane may pro- vide tl e e The principle how er r main tl e me the nu nl er of different type f hydrogen ın a g ven m n ul tıt ıted lkan determ n s how m ny ı m rıc dı ub tituted ısomers are pos- s ble Thus C H ZX (where Z and X may l the ame or d fferent element) represents CH_3CHZX and CH ZCH X and C_3H ZX represent CH_3 CH CHZX CH CHXCH Z, CH CH_2CH_2X CH- XCH CH Z, and CH CZXCH the econd a d thir l be g ıdentical ıf Z and X represe t the me element

In unsatu ated comp unds (simple alk ne and alkynes) the number of un que l catı n for the double r triple l nd determines the numl er f po ıtı n ısome Thus a four-ca bon alkene (r alkyne) ı the s mpl t y tem for which po ıtı nal s m r m ı po ıble CH_3CH CH=CH_2 a d CH CH C≡CH or CH_3CH=$CHCH_3$ a d CH_3 C≡CCH_3

In ymm t ıcal cy lı y t m (cycl alkane a d b nzene) all hyd ogens are eq alent and o s w th eth ne t le t two ub tituent m t be p es nt fo the exı tence of p tı al ı m r The number of s ch som r d pend ▪ the ıze f the ▪ g when th numb r of sub t tı ents (f r xampl Z nd CH) ı l m ted t two Thu ther ▪ tw d ubst tute l yclopropanes (1 1 and 1 2) thre d b tıtut d cy l butane a d cy lo- p ntane (1 1 1 2 and 1 3-) and f r dı ul tı t ted ycloh exa e (1 1 1 2 1 3- a d 1 4-) The n tur f the l enz ne r ng limits dı ub t t ted b n e es t three 1,2 (tho) 1 3- (met) and 1 4- (para) Wher th r three ıdentic l bst t ı nt C_6H Z three p ıt nal ısomer are p s bl (1 2 3- 1,2 4- a d 1 3 5-) b t f r C_6H Z X th e are fi (1 Z- 2 Z- 3-X 1 Z 2 Z- 4-X 1 Z- 3 Z 2 X 1 Z- 3-Z- 5-X 1 Z- 4-Z 2 X) A meth d for d term n g th ab o- l te p s t o of su h b t t ents ı b n ne de- ▪ ds up n the e pe ım ntal p oduct ▪ f p ı t on l ısom fr m a g en d s b t t t d ben (Ko n s meth d)



Cycl prop   Cy l b ta   C loh an   B nz ne

Wh r y l sy t m n t ymmetr cal (cyclo- lk e het orycl ▪ mp und b a d poly ycl y tems s h d c l n a d n phth l n) th p r e t h d ca b n pos e es m th n e typ of hyd ogen t m nd he p ıt n l ı om r sm ▪ ▪ w th b t e ub t t t wh e s poly b t t t l ds t g e t r mult pl ıty of p s t ▪ me th n n ymm tr c l y l yst m

ing agent will cause coagulation Likewise vi cos ity changes often reach a minimum at or near the *isoelectric point* *See* COLLOID ELECTROPHORESIS ION PERMEABLE MEMBRANE PROTEIN [W O M]

Isoelectronic sequence

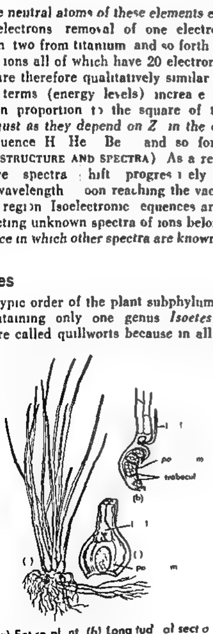
A term used in spectroscopy to designate the set of spectra produced by different chemical elements ionized in such a way that their atoms or ions con tain the same number of electrons The following sequence is an example

Designation of spec trum	CaI	ScII	TiIII	VIV	CrV	MnVI
Emitting atom or *ion*	Ca	Sc^{+}	Ti^{++}	V^{+++}	Cr^{++++}	Mn^{+++++}
Atomic num ber *Z*	20	21	22	23	24	25

Since the neutral atoms of these elements each con tain *Z* electrons removal of one electron from scandium two from titanium and so forth yields a series of ions all of which have 20 electrons Their pectra are therefore qualitatively similar but the spectral terms (energy levels) increa e approxi mately in proportion to the square of the core charge just as they depend on *Z* in the one elec tron sequence H He Be and so forth (*see* ATOMIC STRUCTURE AND SPECTRA) As a re ult the successive spectra hift progres i ely toward shorter wavelength oon reaching the vacuum ul traviolet region Isoelectronic equences are u eful in predicting unknown spectra of ions belonging to a equence in which other spectra are known [F A J]

Isoetales

A monotypic order of the plant subphylum Lycop sida containing only one genus *Isoetes* These plants are called quillworts because in all 64 spe



Isoet s (a) Ent re pl nt (b) Long tud al sect o of l f base (c) Face ew of ventral urface of leaf ba e (From A J Eam s n E W S att a d K S W l Bot y Pr c pl s and Probl ms 5th ed M G w-H ll 1955)

cies the leaves are long and narrow with a poon like ba e spirally arranged upon an underground cormlike tructure *See* STEM (BOTANY) Mo t pe cies are emiaquatic although a few are terre trial. They are confined to the cooler regions of the world

Morphologists differ in their opinions regarding the relation hip of the group They are like the Selaginellales in having ligule two kinds of pores (hetero porous) and in producing two kind of gametophytes They are different from the other Lycop ida in having multiciliate perm in lacking a *suspensor (a chain of cells which serve to put* the embryo in a favorable position in relation to its food supply) and in pos e ing a econdary meristem which develops ome econdary ti ue (*see* MERISTEM LATERAL) The presence of a pe cial root producing region which develops new di chotomous (forked) root each year together with their anatomy sugge ts a *clo e relation hip with* the fo il Lycop ida e pecially the genus *Pleuro meia* The phylogenetic connection between *Pleuro meia* and *Isoetes* i accepted by many botani ts and for this rea on the families Pleuromeiaceae and I o etaceae are often included in the I oetale *See* PALEOBOTANY PLEUROMEIALES TRACHEOPHYTA [P A V]

Bibliography *See* LYCOPSIDA

Isoleucine

Isol ucine

Ch l f l
pK (COOH) 2 3 pK (NH) 9 68
I select po
Sp lro on [ ] (H) +1 4 [ ] (5 N HCl) +39 5
Sol t l (g 100 ml H)) 4 1

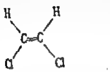
An amino acid considered e ential for normal growth of animals The amino acids are characterized physically by the following (1) the pK or the dis ociation constant of the various *titratable* groups (2) the i oelectric point r pH at which a dipolar ion does not migrate in an electric field (3) the optical rotation or the rotation imparted to a beam of plane polarized light (frequently the D line of the odium spectrum) pa ing through 1 decimeter of a olution of 100 grams in 100 ml (4) *olubility* *See* EQUILIBRIUM IONIC I OELEC TRIC POINT OPTICAL ACTIVITY SPECTROPHOTOMET RIC ANALYSIS

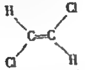
The bi synthe is of i oleucine occurs when pyru ate and α ketobutyrate react to form α aceto α hydroxybutyrate which undergoes rearrangement and reducti n to $\alpha\beta$ dihydroxy β methylvalerate Dehydration t the α keto acid and tran amination compl te the bi ynthe is (*see* AMINO ACIDS) Mo t r all of the enzymes concerned al o catalyze the a alog u rea ti ns in valine bi ynthe i *See* VALINE

During metab lic degradation the fir t te are de mination and oxidati e de arboxylation form ing α m thylbutyryl coen yme A (α methylbutyryl CoA) The f ll wing equenc take place

plane ring serves as a reference point in the molecule and such isomers are called geometrical isomers

Cis-trans isomerism In any alkene system where the doubly bonded carbon atoms each carry two different atoms or groups cis-trans isomers are possible; that is, two similar atoms or groups may lie on the same side (cis) or opposite sides (trans) of a plane bisecting the alkene carbons and perpendicular to the plane of the alkene system, for example



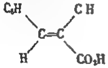


cis-1,2-Dichloroethylene trans-1,2-Dichloroethylene

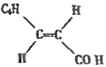
The rigidity of the double bond prevents free rotation, and thus the two geometrically different isomers constitute distinct entities which cannot be interconverted without the expenditure of sufficient energy to destroy the essential character of the double bond

Such isomers will differ both in chemical properties and in energy content, the trans isomer usually the more stable thermodynamically. Evidence in support of the latter statement is found in the ... of the equilibrium mixture ... of the trans isomer whenever either form is subjected to conditions permitting interconversion (high temperatures, catalysts, ... photochemical ... radical ... mechanism)

In designating particular isomers as cis or trans the proper reference points must be used; preferably ... of the alkene bond should carry ... atoms or groups so closely related that no ambiguity is possible (e.g. ... Cl, CO_2H and CO_2R, or CO_2H and CN). Thus the α-phenylcinnamic acid

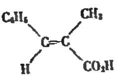


is derived from ordinary (trans) cinnamic acid

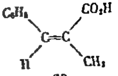


... the ... be called ... of it ... Actually the designation ... the ... group common to both alkene carbons is the phenyl group

Syn-anti isomerism Geometrical isomers that do not carry ... closely related atoms or groups on the alkene bond ... be named unambiguously using cis-trans nomenclature. For example the methyl ... (IV) and (V)

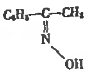


(IV)

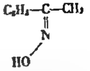


(V)

and the oximes of acetophenone

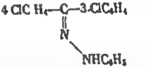


(VI)



(VII)

cannot properly be called trans or cis. Therefore the terms anti (on opposite sides) and syn (on the same side) are used. The larger (or chemically more reactive) group is taken as the reference point (C_6H_5) and the functional group CO_2H in (IV) and (V), OH in (VI) and (VII), is said to be anti (IV) and (VI) or syn (V) and (VII) to it. Thus (IV) is anti-α-methylcinnamic acid, (VI) is anti-acetophenoneoxime, and (V) and (VII) are the corresponding syn isomers. Syn-anti isomerism will be encountered throughout imine chemistry in so far as the doubly bonded carbon carries two different substituents, but it may be necessary to specify to which substituent the nitrogen substituent is syn or anti, thus in

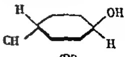


the phenylamino group is anti to the 4-chlorophenyl and syn to the 3-chlorophenyl. Similar situations may obtain in syn-anti isomerism among alkene compounds

Ring isomerism If substituents are attached to alkene carbons which are part of a cyclic system the ring of which contains fewer than eight members, for example, 1,2-dichlorocyclohexene, bond lengths and bond angles prevent the existence of the trans structure. In naming such substances it is not necessary to specify, and the cis designation is not employed

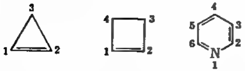
However cyclic structures admit of geometrical isomerism in another sense: substituents may be placed on the same (cis) or opposite (trans) side of the plane (arbitrarily) defined by the atoms of the ring. These are the geometrical isomers cis-4-methylcyclohexanol (VIII) and trans-4-methylcyclohexanol (IX)

(VIII)

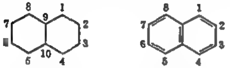


(IX)

Thus there are two monosubstituted cyclopropenes and cyclobutenes (1 Z- and 3 Z) three monosub stituted pyridines (2 Z- 3 Z and 4-Z) three monosubstituted decalins (1 Z 2 Z and 9 Z) and two monosubstituted naphthalenes (1 Z and 2 Z-)



Cyclopropene Cyclobutene Pyridine



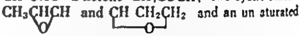
Decalin Naphthalene

Naphthalene illustrates the effect of polysubstitu tion on positional isomeri m in unsymmetrical cyclic system In the parent hydrocarbon posi tions 1 4 5 and 8 are equivalent and are desig nated α positions 2 3 6 and 7 are designated β The introduction of a substituent *Z* in either an α or β position destroys the equivalence of all other positions thus there are no fewer than 10 posi tional isomers for a naphthalene bearing two identi cal substituents Z (1 2 1 3- 1 4- 1 5 1 6 1 7 1 8 2 3 2 6 and 2 7) Where the two substituents Z and X are not identical four of the listed isomers each provide a pair since an interchange of sul stituents in the 1 2 1 3 1 6 and 1 7 structures each provides a new isomer making 14 in all Higher order substitution enormously increases the num ber of positional isomers but in naphthalene as well as in the other types of unsymmetrical cyclic systems the principle governing the total number of positional isomers remains the same It is deter mined by the number of positionally different hy drogens which may be replaced by other atoms or groups of atoms

Functional group isomerism The presence of multiple bonds or of atoms other than carbon and hydrogen (for example oxygen nitr gen) in an organic compound may give rise to isomers whose functional groups or reactive centers exhibit chemi cally distinguishable properties Thus the formula C_4H_6 may represent 1 butyne 2 butyne (posi tional isomers) methylallene ($CH\ CH{=}C{=}CH_2$) 1 3 butadiene ($CH={CHCH}{=}CH$) 1 or 3 meth ylcyclopropene (positional isomers) r methylene cyclopropane In the same manner the mono alkenes are isomeric with cycloalkanes and di alkenes with alkynes bicycloalkanes and spiranes

The introduction of oxygen to give compounds of the molecular *formula* $C_3H\ O$ may produce alcohols $CH_3CH_2CH\ OH$ and $CH_3CHOHCH_3$ (positional isomers) or an ether $CH\ CH_3OCH_3$ When the carbon content is greater positionally i omeric ethers are possible as well Likewi e the introduction of nitrogen may lead to functional group i omers thus $C_3H\ N$ repre ents *n* and i opropylamine $CH_3CH\ CH_2NH_2$ or (CH_3) $CHNH_2$ chain isomers ethylmethylamine CH_3 $CH\ NHCH_3$ or trimethylamine $(CH_3)_3N$ These three amines are functionally different and are classed as primary secondary and tertiary re spectively

Where the molecular formula is $C\ H\ O$ fur ther possibilities for functional group i omers ob tain Thus C_3H_6O represents an aldehyde CH_3- $CH\ CHO$ a ketone CH_3COCH_3 two cyclic ethers



and an un aturated alcohol $CH={CHCH_2OH}$ Likewi e $C_3H\ N$ rep resents three aldimines $CH_3CH\ CH{=}NH$ CH_3 $CH{=}NCH_3$ and $CH_2{=}NCH_2CH_3$ a ketimine $CH_3C{=}NHCH_3$ azetidine $(CH\ )_3NH$ two eth yleneimines $(CH_2)_2NCH_3$ and $[CH\ CH(CH_3)]$ NH and two unsaturated amines $CH_2{=}CHCH$ NH and $CH={CHNHCH_3}$

Where two or more heteroatoms (atoms other than carbon and hydrogen) are pre ent the pos sibilities for functional group i omerism may be illustrated by the following structures wherein Z represents OH *O* alkyl halogen or NH

CH_3CH_2COZ	$CH_3CHZCHO$	CH_3COCH_2Z
(I)	(II)	(III)

Where Z is OH (I) represents an acid (II) a hydroxyaldehyde and (III) a hydroxyketone where Z is *O* alkyl (I) is an ester (II) an alkoxy aldehyde (ether aldehyde) and (III) an alkoxyke tone where Z is halogen (I) is an acid halide (II) a haloaldehyde and (III) a haloketone and where Z is NH_2 (I) is an amide (II) an amino aldehyde and (III) an aminoketone Furthermore within each series regroupings of the con tituent atoms are po sible for example where Z i OH the atoms of (I) may be rearranged to repre ent arious ethylene and propylene oxides (three and four membered cyclic ethers) with a hydroxyl ub stituent or the OH group may be broken up to form methoxyacetaldehyde $CH\ OCH\ CHO$ or the esters methyl acetate CH_3OCOCH and etl yl formate $CH_3CH\ OCHO$

Geometrical isomerism In the molecules of the e isomers the atoms are attached to each other in the same order but with different spatial or geometrical orientation The explicit geometry im p ed up n a molecule by the pre ence of a doul le bond betv een carbon atoms or l etween carbon and nitrogen or by the pre e ce of a ring sy tem (wl ch f r convenien e may l e considered planar how e er *see* CONFORMATIONAL ANALYSIS) make p sible the exi tence of the e i omers Thu two at ms or gr ups f atom attached to each of two different carbons may be relatively clo er t or farther from each othe depending n the re pe tive directions of the bonds fr m the carl ns to wl i h they are att l d The rigid d ul le l nd r

lectr s, y r) r y os tron electr n pair
y be m tted from th atom i uch trans t ons
The half l fe of an i m r and the u der of the
mult pol radiat o em tted a e intimat ly e n
nected w th the d fference betwe n the sp n or an
gula m m t m f th nucleus in the i omeric
state a d the p n of the energy l l to wh ch it
dec Th half l fe al n depend upon the tran
no e gy b t f r a energy the half life
will be several d rs of magnitude long r for e ch
add u l unt of pi change

Se MULTIPOLE RADIATIO RADIOACTIVITY

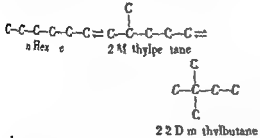
[D E A]

Bibliog aphy S Flu gge (ed) *Handbuch de Phy k*, v l 4 1957 K S gbahn (ed) *B ta a d Gamma R y Spect scopy* 1955

Isomerization

R arrang m t of the atoms within hydr carbon mo ec l s. Isom zat n p oc es of practical gnifi a e in pet leum hemi try are (1) mi gr t l alkyl group (2) h ft of a ngle-carbon bo d in phth ne and (3) double-bond h ft in l fin.

Migration of alkyl groups An ex mple of alkyl gr pm grat n (k let l i mer zat on) s



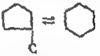
Isom izat t m e h hly b a ched c nfigu a t s h mme c l imp rt n e s nce it esults in (1) imp o ement in c mbu t on quality n the a t m bile ngin as me s d by tane n mbe and (2) a ed ch mical r a ti ty be tter b rr e rbo t m ult. Th *unleaded moto* m thod octane numb f the abo h an i o- ers ar *6 0 3.5* and 93 4 respect ely N rmal butane c n e ted to i but ne (wh ch has te tiary a bon tom) t att h mical rea t ty th l fins lkyl t r t whe n-b t n is inert.

Isom rizat of p ffi s s a ever ible fi t rder r a ti n l m t d by th rmodynam q l b- rium wh ch f rs i ed l ran h ng at lowe temp t e U des abl ck ng ea ti n l ad ing to talyst de t t n o u at h ghe tem per ures. Th y a e lled by dd g a c a k ing upp esso s h as hyd gen

Conv rs n f n rm l buta e to sob ta e is th mm c l f i om izatio U ually t carried ut i th r l q d r po ph o e m um hl id ataly t pr moted w th h d o- gen hl d In th v p r pha e p oces (250- 300 F) th l m um hl r d ft s pp t d on b ux e. I th l qu d ph proce s (180 F) t i di ol ed in molten ant m ny trichloride or used in the form f a *liquid compl x with hydro- c rbon* A sec nd type f ataly t for apor pha i om rization (300-850 F) is a n l l metal u u ally platinum upp rted on a carr er This may l e alumina with hal d *added to* pro de an acidi sur *face All the pr cesses are select e* (95-98% to *isobutane) App oximately* 60 f the n l ut ne feed i con erted per pas to i i itane in the liquid pha e pr ce

I pentane a h gh-o tane comp nent u ed i aviat n ga li e is made ommercially by omeri zat on f n pentane Pet leum naphthas nt in ng fi e and i carbon hydrocarbon also *re i omer* ized commercially for imp ment n m t r f el ctane numbers N ble-metal catalyst is normally u ed with higher m lecul r weight fe d Isomeriza t n of p raffins bo s x ca bon toms i of le s mportance s nc octane imp em nt i limited by p edominance f m nomethyl b anch ng at quilib- r um. Skeletal i omerization is an important sec ondary r acti n in catal t c cracking and cat lytic reform ng. Aromatic *and ol fin undergo skeletal* is merizat n as do pa affns

Single carbon bond shift *This* p oce s, *in the* ca of aphth es i illust ated l y the reacti n



M thyl cyclopentane Cyclo h x ne

Cycl hexan nd meth l ycl hexane *ha e* been p odu ed c mm rc ally by liquid pha e i m za *t on of the fi e-ca bo* i mer o r al minum chlo ide-hydrocarbon-complex catalyst prom ted *by hydrogen chl ride Con e ion per pass* i *higl* sel ti ity e ell nt a d *reaction cond ti* m ld (190 F) Cycl hexane s *raw mate ial lo m k ing nyl n* nd t may b dehydr ge at d t l en zene Methyl ycl hexane has been u ed *to m k synth tic nit* ati n g ade t l e e

Shift of a double bond This pro s is f lly applied wh n a pecifi ol fi i needed for chem cal ynthes f ex mpl

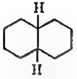
$$\mathrm{C{-}C{-}C{=}C \rightleftharpoons C{-}C{=}C{-}C}$$

1 B t ne 2 B t ne

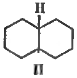
Do bl b nd h ft oc u s lect ely e d c ataly ts at *temperatu es bel w 450 F Howev r* th pr port n und go ng keletal om rizat n in rea e t mp r tu e is n a ed *u til t tem* p rat es in the rang 600-950 F equil brium app o ch d at fai ly h gh spa elo itie *Fq il b- ri m f v* m eme t of do ble bo d t the mo stable int l p t on (85 % 2 but ne at 400 F) a d cta e imp ment a c mp n es th sh ft how e the n ea n rm lly is i ffi ient t j st fy the t f p e ng th mally cr k d g s l nes l ly f th s p p Th typ f om izat n o u a c nd ry n t on i th t lyt c kı g nd c t lyt c p lymerizat n

The geometrical designations are referred to the principal (lowest numbered) substituent in the present instance the hydroxyl

Bicyclo[x y 0]alkanes (for example bicyclo [4 4 0]decane decalin) may have either a cis or trans ring junction (if the rings are sufficiently large)

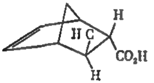


ci Decalin

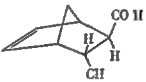


t ns Decalin

However in bicyclo[x y z]alkanes notably Diels Alder adducts of cyclopentadiene with substituted alkenes only cis ring junction is possible and the designations endo and exo are used respectively to locate substituents trans (anti) or cis (syn) to a bridge Thus in (X) the carboxyl is endo and the methyl exo whereas in (XI) they are reversed



(X)



(XI)

Two further geometrical isomers are possible in this system one in which both sub tituents are endo and the other in which both are exo

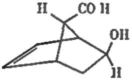
The terms cis and trans syn and anti al o find application in the bicyclic systems Thus (XII) and (XIII) and (XII) and (XIV) may be considered syn (XII) and anti (XIII XIV) isomeric pairs and the prefix anti may be affixed to both carboxyl and hydroxyl in naming (XV) All four are geometrical isomers *See* OPTICAL ACTIVITY STEREOCHEMISTRY TAUTOMERISM [W R V]

Bibliography H Gilman *Organic Chemistry* 2d ed vol 1 1943

Isomerism nuclear

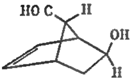
The metastability of excited states of atomic nuclei While all excited states of atomic nuclei have finite half lives isomers are defined as atoms who e nuclei exist in excited states for measurable lengths of time (*see* EXCITED STATE METASTABLE STATE) Isomeric half lives as short as 10 sec and as long as several years have been measured The total energy of the nucleus when in an isomeric state may be from a few thou and to a few million electron volts greater than the energy of the nucleus in its ground state

Nuclear isomers may decay by β ray po itron or α particle emission or by the capture of atomic electrons but most often they lose their energy by making transitions to lower energy levels or to the ground state of the same nucleus Internal conver



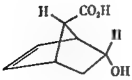
(XII)

e o 2 Hydroxyl icycl [2 2 1] 5 l epte e *syn* 7 carl o ylic acid
syn 2 Hydr xyl y lo[2 2 1] 5 l eptene *syn* 7 ca l xyl c ac d



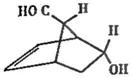
(XIII)

exo 2 Hyd oxyl i y l [2 2 1] 5 l pten *ant* 7 b yl c a id
syn 2 Hy l yb yel [2 2 1] 5 l ept ne *nt* 7 ca l xyl acil



(XIV)

end 2 Hydroxyb yel [2 2 1] 5 l epten *syn* 7 arl oxyl acid
t 2 Hydro yl y l [2 2 1] 5 l pt *y* 7 l oxyl acid



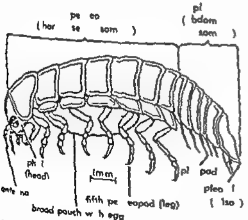
(XV)

do 2 Hyd yb cycl [2 2 1] 5 l epten *t* 7 rl oxyl c d
anti 2 Hydro yb y l [2 2 1] 5 l ptene *nti* 7 arl xyl c ac d

ally n nıu t on th p-amın alicylic acid and str pt myc n H wev ı ıproniazid s now used a a p h c nerg z n t t eat b th mild and e ere de-p ess o s and p ych es a c ated w th evere e-pres n o eg ess ns. *Se* P YCHIC ENERGIZER P YCHOSIS Se als CHEMOTHERAPY TUBERCU LO IS. [N J C]

Isopoda

An rd r of mala o tracan crustac an wh ch are chara t ızed by ha ng ceph l n r head bea ıng o e p ı of ma ll peds ın add tı n to the a ı ma d bl and ma ıllae The maxill peds te d rıved f om the legs of th fir t po tcephalic som te wh ch lmo t c mpletely f ed with the eph l n A apa ıs l ckı g Tl e perae n or th x, e t of seven d t nct om t s e ch b ar ıng p r of p re opod the legs The fi t pa r of pe opod ı n er helat a d typ c lly all pa rs f pe pod e m lar n tructu e The ple r abd m n ha ı m te The fir t fi e pair f ple al appe d ges ar f l aceous The la t p ır ıs mod fied t ha dened ppe dage called u opods ı d th la t som t s f ed w th the t l on ınt a pleot l n Att ched to the ınner ba e of the p re o-pods f the fem l ar platel ke app nd g s alled oost g a Pro to egg depo ıtı n the o t gıt enl rge a d ı t rle ı t form a b ood p ch nt hı h th egg are d p ıt d L rval dev l pment o urs ın th wh le t ıs in the brood pouch m rs p m Th you g hat h f m the egg ınt the b ood p u h fr m h ch th y m g mın atu e adults lackın only the eventh p ı f perei p d These a e add d du ng few po teml v nı m lt Th r o pa ental ar of the hat hed y g The ld the ry th r th y ung ec r e no r Lhment f m the pa e t ha b en ab nd ed The se es a e p te f rt l zat n ı ınte al and the mber of egg p odu ed u ally l s tha 50 The f m l th ally h te zygo nd du l b t l ıtl ı kn wn f th g n t s of opods



L ony f m le p d (F om R J Me Th om b l gy f th w d-b g p d st Lımno ıa M m f C mp t Zo l gy H rv d C lleg 8 ll 112(5) 363–388 1954)

Ecology Th m st familiar ı op ds are the ter re t ıal sow bugs or pill bug Many f the e a ı mals r ll up ınto a c mp act ball when dı turbed Land ı pod are u ually f und ın moı t en ıron ments under d caying lea es and wood and under rocks I pods range ın size from 1 mm (*Munna*) to around 20 cm (*B thynomus*) In addition to l e-ıng found on land ı op ds ha e been found ın h t springs (*F sph eroma therm philum*) and m sul terran an fre h waters (*Caecidotea*) and ca e The majority a e marine where they range fr m the ın t rtidal area t the g eat st depths of the Their food aries from wood (*Lım oria*) and ea weed (*Lım oria* and *Idothea*) t animal fle h (*Cı ola a* and *Cymothoa*) *Cı ola a* has been kn wn to ınflı t small but painful wounds on swim mer *Cymothoa* and t all es are predaceou comme sal and para ıtic on fi h The de truct e mar ne wood bor ng ısopod *Lımnoria* the gribble causes annual damag e tımat d at $ 000 000 t wharf p ling n the United States and one species ı repo ted to att ck treated timber

Geolog c lly ısopods are an an ıent group rang ı g from th De on an to the Rece t The genus *Cyclosphaeroma* fr m the Juras c of England ı the be t k own ısopod foss l and belongs to the o temp r ry fam ly Sph erom dae

Classification Th cla ıficatı n of the Isopoda ıs not tab l zed f r example the gnathıids a d a thurid are ncluded ın the suborder Flabel lifera by ome ın estigato nd not by othe Tl e s a ne d f r crıt cal re ar h on the gener alıties of th ı la s ficat M t tudents dı ide the opods into seven equ ale t ub rders the Onı c dea V l if ra Flabellife a Bopyr id a Gnath ode As llota and Phreatoıc d a

The On s de a e the pill b w bug and wood l ce wh h a e t r e trı l Some ha e ps udo-tr h a on ple p d nd the urop ds a e terminal *Oniscus Po cell* o and *D t* a e c mmon example

Val ıfe a e marin and fresh w ter specie with al el ke opods ı flexed u de the pleon and c e ı g the pleop d The m nd bles lack a palp Th nım ls su h s *Idothea* a d *Arct s* ar fre l vı g

The Flabell f a a ma e nd fre h w t r sp c es with the uropod exp ded lat rally w th the ple n to form a ta l fan Thes an mals re f e l ng p edaceo s c mmen al and para ıtic *C la a Cym th a, A thu a* nd *Lım ori* re c m mon ge

B pyr d are mar ne para t s c u ta eans The young a e m cl l ke ll bell fe n but the d lt f m le s metamo phos d ınt a leafl k ac nd the male ı m ute with many parts redu ed E mpl a e *Bopy s* and *Io e*

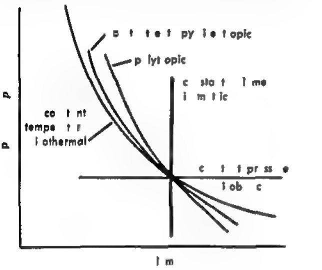
Gnath de a 10-leg d m ı pa a t s f fi h with later l ur *pod Th fem l m thparts* ar t l wh le th m l mand bles a e p nce l ke and p oje t b y nd th fro t l marg n of the cephalon a ın *C th*

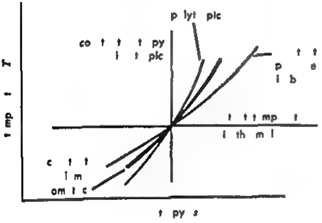
A ll ta a m ll ma e and f esh w t pe-es Th r p d e styl f rm nd t rm nal Ex

processes in part accounting for the high octane numbers of the gasolines *See* ALKYLATION AROMATIZATION CRACKING ISOMERISM MOLECULAR PETROLEUM PROCESSING [G E L]

Isometric process

A constant volume frictionless thermodynamic process in which the system is confined by mechanically rigid boundaries Because no work can be done on the surroundings by a system with rigid boundaries the heat transferred to the system equals the increase of internal energy stored in the system This increase of internal energy in turn is a function of the specific heat and the temperature rise of the system





Isometric process compared to other thermodynamic processes

$$Q = U_2 - U_1 = m \int_1^2 C_v \, dT = m \int_1^2 T \, ds$$

where Q is the heat transferred at constant volume U is the internal energy m is the mass C_v is the specific heat at constant volume T is the absolute temperature and s is the entropy The diagram shows that there is an increase in both the temperature and the pressure of a constant volume of gas as heat is transferred into the system *See* THERMODYNAMIC PROCESSES [J B]

Isomorphism (crystallography)

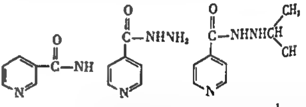
A similarity of crystalline form between substances of similar composition Two substances which are isomorphous have a similar chemical formula an equal or nearly equal ratio of cation to anion radius and comparable polarizabilities of their ions. Isomorphism is morphotropism in a narrower more precise sense (*see* MORPHOTROPISM) Similarity in the macroscopic characteristics of isomorphous crystals becomes so close that extreme precision is needed to distinguish between them

Examples of isomorphous substances are $NaNO_3$ and $CaCO_3$ $CaAl_2Si_2O_8$ and $NaAlSi_3O_8$ and $BaSO_4$ $SrSO_4$ and $PbSO_4$ Substances such as ThO_2 and Li_2O are anti isomorphous they both have the calcium fluoride structure but the positions of the anions and cations are interchanged in the two structures because of the relative sizes of the ions Isomorphous substances form mixed crystals while anti isomorphous substances do not For a discussion of the chemical composition and crystal structure of isomorphous minerals *see* MINERALOGY *See also* CRYSTAL STRUCTURE [W D]

Bibliography R C. Evans *Introduction to Crystal Chemistry* 1939 A E H Tutton *Crystallography and Practical Crystal Measurement* 1911

Isonicotinic acid hydrazide

A chemical compound used as a chemotherapeutic agent for certain infectious and noninfectious diseases The observation in 1945 that the vitamin nicotinamide inhibits the growth of the bacillus which causes tuberculosis led to a search for similar activity among compounds chemically related to nicotinamide The direct outcome of this search has been the discovery of two drugs with outstanding potency against the tubercle bacillus isonicotinic acid hydrazide (isoniazid) and its isopropyl derivative (iproniazid) The chemical structures of these compounds are as follows



Nicotinamide Isoniazid Iproniazid

Isoniazid and iproniazid are highly specific in their action against the tuberculosis organism (*Mycobacterium tuberculosis*) They have proved inactive against a large number of other bacteria protozoa and viruses upon which they have been tested In the treatment of human tuberculosis iproniazid is no longer used because of toxic effects produced during its chronic administration This toxicity may be due to the inhibition of monoamine oxidase an enzyme with which isoniazid does not interfere Thus isoniazid alone enjoys widespread usage in the treatment of human tuberculosis

Fig 1 A p   o f u d th t t of t m t (K I t   ) th   sary t th I f f som term es   th y t nzym s wh h d g t illu- lose th p c p l food f thes t m t G tly m g fied (F m T E S yd O E emy th T m t C # k 1935)

i juri u to f rest, f uit and hade trees tea bushes li ld er p and grass on the veldt Their d mage to truct res f man and their content is er us e en i temperate regi ns In the United State this an u l l is e timat d at $100 000 000 *See* HYPERMASTIGIDA

Termite castes Term tes are p lymorphic. Ther are males female and three types of re- producti e f rm the monogam s winged f rms with fu cti n l eyes the p lygam u forms with wi g pad and the polyg mo s wingle forms (F g 2) A ■ es of intermed ates incl ding fer t le o-called soldie s also occur The e may be th ee (Fig 3) t fi e types of ter le mal or fe- mal soldiers and tw types of sterile male fe m le w rke They are usu lly blind There is ■ at di er ty of kinds nd great stru tural dif fe e c between the ca tes Intere stes also occur b tw n wo k s a d ld er Th re is no worker c te am ng the mor p mit ve t rmites nd nymphs take er the r duties Amo g ne highly sp cial zed term te n ldi ■ ca te occurs As a r le where w rke do occur they onstit te the m st umero te n the c lony for the greater port o f the year wh re oldi rs c titute b ■ mall proporti n of the ol y At ertain easons of the year i the Un ted States all types of the ep odu ti e form occu in ery large umbers

D is n of l b r The is a di is ■ of labor with b th r p odu t e nd sterile form *present in* the ol y Th ep oduct es keep the col y ali e The wo kers whi h ha e ev l ed f m the soldier a te rep r the nest nd ■ e for and feed the yo ng th rep odu t f rms d the sold ers

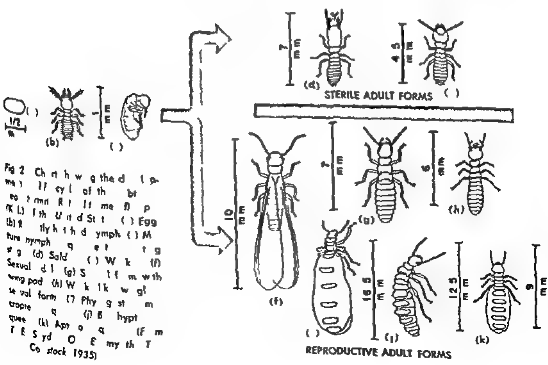


Fig 2 Ch rt h w g the d l p- me) lf cy l of th bt eo t rnn R t lt me fl p (K L) f th U n d St t ( ) Egg (b) ■ tly h t h d ymph ( ) M ture nymph q e l t g s g (d) Sold ( ) W k (f) Sexual d l (g) S l f m w th wing pad (h) W k l k w gl se val form (? Phy g st m tropte q (j) B hypt quee (k) Apt o q (F m T E S yd O E my th T Co stock 1935)

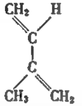
ternal pleopods are operculate and cover the other pleopods *Asellus Ianira* and *Jaera* are genera of this suborder

Phreatoicidea are laterally compressed isopods living in the fresh water streams of New Zealand and South Africa In general aspect they look much like amphipods

About 3000 species of isopods are known today but it may be estimated that only one half of the existing species have been described See CRUSTACEA [R J M]

Isoprene

A five carbon conjugated diolefin or diene having the structure

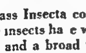


Isoprene

It does not occur naturally but is obtained by the destructive distillation of gas oil naphthas and rubber It is also prepared by the catalytic decom position of dipentene It is commercially available in about 96% purity and is used in the production of butyl rubber

The terpenes may be regarded as multiples of the isoprene unit C_5H_8 Indeed isoprene may also be the foundation for other important plant products such as phytol the sterols and the carotenoids

Isoprene is a mobile colorless liquid boiling at 34 1 C having a specific gravity of 0 862 It exhib its all the characteristic reactions of dienes of this type Isoprene polymerizes readily to form dimers and high molecular weight resins The principal dimer formed is isopropenyl methyl cyclohexene



Polymerization of isoprene during storage can be controlled by avoiding contact with oxygen by using inhibitors such as *tert* butyl catechol and by keeping it at low temperatures See DIENE TERPENE [E L S]

Isoptera

An order of the class Insecta commonly known as the termites These insects ha e wings of equal size biting mouthparts and a broad thorax otherwise they are superficially antlike They are ocial in sects which live in large colonies with a caste sys tem and division of labor Termites are closely re lated to the cockroaches and there prol ably was a common ancestor therefore termite have been termed social cockroaches The primitive Aus tralian termite *Mastotermes* has wing structures and an ovipositor similar to tho e of the cock roaches The method of mating in the e two groups is similar with the apices of the abdomens oppo ed Most termites lay their eggs singly but the primi tive forms lay them in a mass like the cockroaches, which produce an ootheca (self generated protec tive covering or case secreted over the egg ma s by the adult in ect) Furthermore ome primitive cockroaches which bore into wood like termites con tain symbiotic protozoa in their inte tines which by means of enzymes digest the wood the roaches ingest and render it available as food Fo sils of both termites and cockroaches occur in the Pale ozoic era of the Carboniferous period See SOCIAL INSECTS

The colonizing flight of termites is not a nuptial flight but one for dispersal After a short weak flight the males and females lo e their wing and pairs seek favorable ites for ne ts Only after the new colony is founded does mating take place The rate of egg laying is slow at first but tropical queens may lay as many as 30 000 per day the male or king continues to fertilize the queen for life There is no pupal stage but there are quie cent stages of short duration while molting with marked changes from nymph to adult Termite queens have a remarkable post adult growth due to special diet Physogastric queens of African fun gus cultivating *Macrotermes* reach the length of 117 mm With the kings they may live as long as 25 years

Taxonomy and distribution Over 2100 different species in 6 families and about 180 genera are known including 68 fos il species The I optera may be classified as in the following table and in cludes the number of living and fossil species The total does not include new species

Families of Isoptera

F m ly	N mb f spec		
	L ng	Foss l	T t l
M tot m t d	1	16	17
K l t m t d	8	11	93
H d t m t lae	5	1	3
Rh t m t d	151	8	159
T m t d e	13 8	4	133
U l t m t lae	[illegible]	1	1
Do l tf l p	0	16	16
Tot l mbe f spec es	1787	68	[illegible]

Isoptera occur in all zoogeographical regions ex cept the Arctic and Antarctic termites reach the height of their de el pment in the tropics the 50 parallels of latitude and the mean annual 50 i o therms outline their di tribution

Nutrition With advancing civilization termites have changed from scavengers in the fore t to in jurious insects The food of termites i cellulo e wh ch is obtained from both living and dead vege tation Cellulo e inge ted by certain termites is both inge ted and digested by their symbiotic in te tin l protozoa which produce the nece ary en zymes (Fig 1) Other termites lacking protozoa btain their cellulo e in a form more directly avail able as food In the tropics termites are e pecially

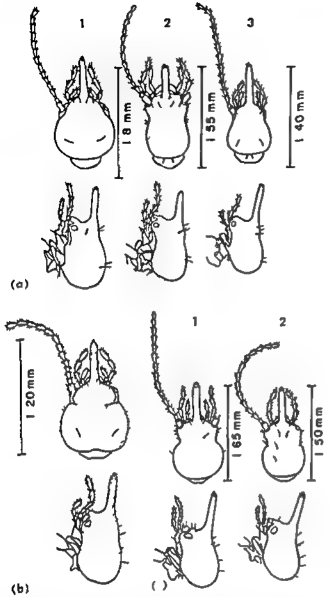
Fg 5 T rmit m u d d tt g th l d g A trol' (H G Hill) (F m T E S yd O E my th T I C mst k 1935)

grooming hab t th t is, the you g l ck exud ti n fr m th bodies f the ad lts

Surplu rep od ct es are l m nated if a p i mary p ir i fu t n g eve if the s n d ct tact t permit th tr smi i f the h b t ry h rm e This s c mpl h d in rt fi al l n in the labor tory by n ry p e pti antenn l ta t th gh lay of fi m tal g u e El m na i n ev occ r if t u h g f a tenn e s pre e ted by t l ye f ga ze ⅛ n f m ch the Termitaria The l tes ne t f term te a c n entr t d the tropi s d d ff d i temp ate r gi n Th forme con t cted f o l r arthl ke mat i l a rt o r n th gr und a trees n a m u ds n o b l w th gr d Th d ff ed nest e with n w d or n the earth They m y be m ed f m ar a to a ea w th h nging e ri m ntal o d t In th tropi wh l l l ges f term tar d t the la d ape (F g 5) The ests r l a d f v u s z d h p s and m y h towers or ll mney Mounds Af rx may b 9 met r he ght M y te m t ia ha e r hedd ng tru tu al d i In Au t l m nd o l ts a nt d w th r fe e c to th n s ays Th r h been a p ogre s e devel pm t in th stru t n f t rm te n t c mpa bl to th r lat foll wed by m n m h t ct es f m a est kysc pe

W th the m e p t tou c nt ated nests th a derly a a g m t f cell a d g l lenes th a pe l r yal h mb fo the p o duct e f rm d nu sert i wh h the egg a d you g r te ded In ests n Indo-M lay nd Af rica galle ies lead to fungu gardens (Figs 6 and 7) whe edible mu h ooms a e cult t d by the t rmi t M und t i South Af ica ha n bee at d by th abo gi es for hu d ed of years In th U ited State l rge c l ny may on t f o ly 250 000 ndi id al whil i the tr pics est m y ontain 3 000 000 inhabit nts There i on t t hythm c act ity d y a d n ght In car

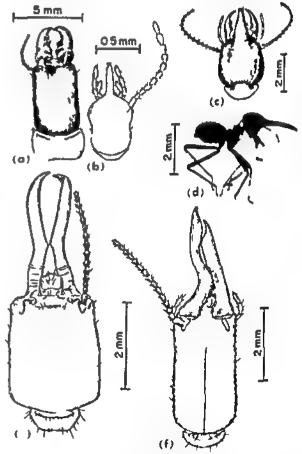
Fg 6 ( ) M d f f g -c h t g t m t f m J ll w g th f g g d (b) C d wh ll th t mt f d th d l p d f m th th dl k my l m f th f g ll t d th g d s (F m T E S yd O ll my th T m t C mst k 1935)



Fg 3 Dorsal a d side views of heads of nasut form term tes to show polymo ph m or d fference fo m of sold ers of the sam spec es (a) Th ee typ s of sold e present majo termed ate and m or (b) O e type of sold er present (c) Two types of soldier pres nt ma jor and m or (F om T E Snyder O r I emy th Te m te Comst k 1935)

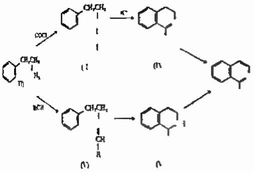
The soldiers defend a colony when it is invaded by ants Primitive soldier termites have sawtooth man dibles (Fig 4) but later there evolved a special gland in the front of the head with an acidulous secretion which superseded the mandibles in many termites Among the termites intermediate between the primitive and highly specialized form both mandibles and frontal glands function In the nasu tiform termites a viscous liquid is ejected as a special and effective form of gas defense In other highly specialized termites the mandibles are mark edly asymmetrical and could not be used for biting but are used audibly to snap or flip the insects away from danger or they may be merely used for signaling to warn of danger The workers and sol diers live only 1-2 years Each year large numbers of winged exual adults leave the colony to found new colonies

Evolution of castes The caste system and the oc currence of sterile forms are difficult to explain un der the various theories of evolution The castes or different types of termites in the same colony are not distinguishable until after the third molt when they can be separated into the sterile and repro ductive forms The determination and regulation of the castes can best be explained by the inhibition theory Males females and soldiers ecrete ecto hormones which inhibit the nymphal development of individuals of the same sex or caste as that of the form secreting the hormone In small colo nies where the primary reproductive adults are functioning fully the development of additional supplementary forms is inhibited by the ecretions of the parent reproductive adults Each ca te if pre ent in the colony in sufficient numbers tends to delay or inhibit the development of individuals of the same caste by a hormone regulation These secretions are transmitted to the young by the



Fg 4 Sold e t rmites from the American tropics w th d ff e t types of def se organs (a) He d of a pr m t ve Kal t mes w th b t g jaws (b) Head f a highly p cial zed s t form te m t w th nasu for def e or ch mical w fa (c) He d of ld er w th both j ws and n sus (d) L t al silhouette view f similar ld er (e f) H ads of old e s dapted for fl ppi g (F om T E S yder O I my th Te m t Comstock 1935)

salts. S b tit tion reactions s h s nitratio sul fon ti br mi at o a d me curat n are b- served



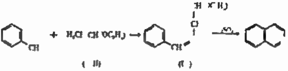
Phe yl thylam (II) re start ng p i t in tw g l yntheses The B schler Nap lsk m thod ycl ze a N cyl ted de at e (III) with phosph rus o y hlor d 3 4-d hyd o qu o- lin (IV) The P ct t Spe gler seque c erts phenylethyl m e (II) by e cti w th a ald hyde to an im e (V) wh ch cy l es the pres en ol mine l a d to 1,2,3 4-t trahydr soq n olin (VI) Dehyd t n f e th 3 4-d hydr 1,2,3,4-t trahyd q l e by chem l ca alyt methods is g ne lly c mpl cated that f lly atu ated isoqu l es (VII) e re d ly obtai ed In n th r k d f ynthesi (P m ran F t h) If i a d ed t y l anil (IX) p od ced by the act of m a e- tal (VIII) nd s m t c ldehyde

When th m ti i g i phe yl thyl m (II) a tivated by ph n l hyd xyl gr p p to the point f cycl zat o the Pi tet Sp gl e- ctio (V VI) oc u s nd r pt ally m ld d t n B o ynthe s of i qui l ne pl t p od ucts p oceed by th s k d f p o es

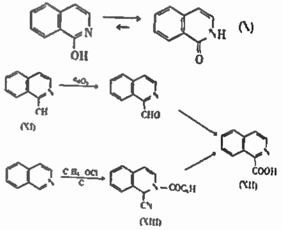
Important derivatives 1 2,3 4-T t hyd i o- qu l nes bt ned i P t t Sp gler sy th ses, r by red ct n f 3 4-d hyd o oqui l es 1,2-d'hyd soqu n line r f lly m ti i qu l es. Furth r hyd oge ats o pl t m c ta ly t nl d i mpletely t r ted de ahyd o- q n l es 1 2 3 4-Tetr hyd oq ol es o tho-substituted b zyl m nes th b c ty of wh ch is compar ble t that f al phati am n

Sulf at on f isoqu l e w th l um g es ma nly -oq l 5- lf c a d H ghe tem p t es g nc g m unts of q l e- 8-s lf n c d d i q l 7 lfon c id Th cti f i q line w th n tr c lf ri d g es ma ly 5-n t qu l e t geth with som 8- t o soqu l e B mi t on nd me u r ti f th 4 po t Sod m de r ts t y eld l m n soq l N leoph l t ty t th isoq l e l po t h w by th sod m de p oces a w ll a by mb t f qu l th g m tall ompou d t gi e l b t tuted deri t es and by th h d e ct ty f 1-h l soq l t d pl m t p es es

1 Chl ro soq i ol nes have en obtained by diazo- tizati n f l amin oquinoli n c centrated hy d chlor ac d 1 Hyd xyisoq n line or i ocar bo tyril e t in aq eo s s lutio almost t rely in the 1-oxo f rm (X) Other hydroxyi oquinoli es deviat l ttle fr m the norm l beha i of phenol 1 Methyli oquinoli and t much les er d g ee 3-methyli oq line po es react e methyl g up Quat r zation enha es thi reacti ity



Is qui line l ca boxyl c a d (XII) h been bta ed d rectly by way of i quinol ne-l-car bo ldehyde by oxidati n of l methyli qui ol ne (XI) The m cid i acces ble fr m i q ino- l e thr gh the Re ert c mp und (XIII) 3-M thyl soq nol n be o di ed with el ni m d xid fir t t i oq n l ne 3-ca bo aldehyd a d th w th hydr gen pero ide t i q in li e 3- arb xyl a d Other i qu ol ne arb xylic a ds are a lable hydroly s p oduct f om th esp nd g ya der ti e all f which can be obta ed by nte ct n f the br moi quino- l ne with cup n ya id Is qu noline 1-ca b yl c ds a e re d ly dec boxylated



With me x ept n the cti s of quino- l e h a al gou c te p t th t on f q l e

[w j ce]

B bl og phy Adams (ed) *O g nic R c t* 1 6 1951 R C. Eld field (ed) *H t o y l C mp ds* l 4 19 2

Isostasy

A theory f hyd st t c equ l b i m th vari us parts f th arth cru t M ny sc nt ts w j dge th theory w ll onfirmed as t be d r d a b law f l gy B F H well J 1959 t ted t in h xpl i t rms all

ton tree nest in Jamaica consisting of 500 000 indi viduals the traffic from the nest through shelter tubes was 8000 per hour during the period of great est activity shortly after midnight

Within the mound nests the temperature and hu midity are higher than outside The humidity may be as high as 92% In nests of the fungus growers air heated in the fungus gardens is circulated through the nest so that the high concentration of carbon dioxide is dissipated through the walls and cooled oxygen rises into the nest In the Lower Congo region of Africa remarkable small ovoid sub terranean *Apicotermes* nests occur with variou progre sive types of ventilation pores

Control For the purpose of preventing and rem edying termite injury these insects may be classed as subterranean dampwood drywood carton and mound builders and harvesting types Damage to living vegetation by subterranean termites can be remedied by saturating the soil with low percent ages of water emulsions of chlorinated hydrocar bons *Structures can be protected against all types* of termites by securing impervious foundations and the use of mechanical and chemical barriers Where dampwood termites injure woody vegetation

Fg 7 Fru t ng body of a f ngus (Agar e) g ow i g f m a b t of the fung s ga d f a J a e term te (Fr m T E S yd r O r E emy th T m te C mstock 1935)

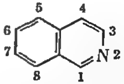
poison dusts may be injected into the galleries Where buildings are damaged by dampwood ter mites dryness should be secured by structural methods Damage to structures or furniture by dry wood termites can be remedied by the injection of poison dusts into the galleries or by fumigation with lethal gases Termites in carton or mound nests can be similarly killed Harvesting termites can be controlled by the use of poison baits or their nests can be poisoned or fumigated *See* IN SECTA INSECTICIDE [T E S]

Isopycnic

The line of intersection of an atmospheric iso pycnic surface with some other surface for in stance a surface of constant elevation or of con stant atmospheric pre sure An isopycnic surface is a surface in which the density of the air is con stant Such surfaces are also designated i osteric surfaces because the e surfaces in which the pe cific volume is constant coincide with the recip *rocal conditions of isopycnic surfaces since* den sity is the reciprocal of specific volume On a surface of constant pressure isopycnics coincide with isotherms because on such a surface density is a function solely of temperature On a constant pre sure surface isopycnics lie close together when the field is strongly baroclinic and are ab ent when the field is barotropic *See* BAROCLINIC FIELD BAROTROPIC FIELD SOLENOID (METEOROLOGY) [F S]

Isoquinoline

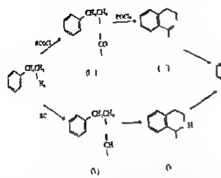
One of a group of organic compounds containing a benzene ring fused to the 3 4 positions of pyridine Isoquinoline (I) is a representative member of the group *See* HETEROCYCLIC COMPOUNDS QUINOLINE Quinoline produced from coal tar contains approxi mately 1–4% of i oquinoline and it is an important ource of the latter material Separation is effected by electi e extraction of the more basic isoquino line *with acid or by selective precipitation* and fractional crystallization of salts Repeated frac tional freezing and distillation have furnished pure isoquinoline Many plant alkaloids especially tho e in the cactus opium and curare groups are iso quinoline deri atives



(I)

Properties and preparation Isoquinoline is a co lorless odorous liquid with bp 243 3 C, mp 26 5 C and n_D^{20} 1 62078 Its stability to acid base *or heat is high I oquinoline which is some*what more basic than quinoline (the pK s are re pec ti ely 5 14 and 4 51) can be protonated to f rm simple salts and alkylated to form quaternary

lts. Sub tit t re ction uch s nit t n sul f n n, b m at o a d me n ation are observed



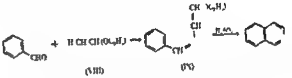
Phenylethyl mine (II) re t rting p mt in two g ne l y the es The Bis hler N p alski method cycl z an N cyl ted der ati e (III) with ph ph ru o y hl d t 3 4-dihyd o soquinol (IV) The Pi t t Spengler eque ce on erts ph lethylamin (II) by eact on with aldehyd t an im n (V) whi h ycl z s in the p esen f min ral acid to 1 2,3 4-t tr hyd o soquinoline (VI) D hydroge at n f e ther 3 4-d hydro 1,2,3 4-t trahyd o qu n l e by hem l r c talytic method is g n r lly un ompl c ted that fully n s tu ated i q nolines (VII) e readily obtai ed I n th ki d of synthes s (P me anz Frit h) ull c d ed t cy l e a il (IX) p od ed by th rea ti of mi o e- lil (VIII) and r m t c ald hyd

When th om t r g ph yl thyl m e (II) a t ated by a phe ol c hyd y) g p p t th po nt f cy lizat o the P tet Sp gl r reci n (V VI) oc s u d x ept lly mild o d t s B o ynth s of oq n l ne pla t p d ucts p oceed by th ki d f pr ces

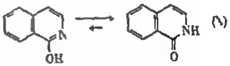
Important derivatives 1 2 3 4-Tetr hydr oq l ne ar bt ed n P t t Spengl r yntheses, o by red ct n f 3 4-dihydroi qu l es 1 2-dihyd o soq lines or fully omat oqui oli es. F rth r hydr g n ti plat m c t l t an l ad t mplet ly t ted dec hyd oquin li e 1,2 3 4-T tr hydroi oqu ol nes a e o those b tituted benzylam m th b city f whi h is comp ble t th t of liphati ami e

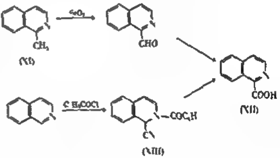
S lf n ti of q l n w th ol um g ves mai ly soqu l ne-5- ulfo ic cid H gher t mperatu es g inc amo nt of i qu n l ne-8- l c d d i oqu l 7 lf m a id The rea ti n of qu n l w th n t c lf r id g es ma ly 5- t soq n l tog the w th some 8- t isoquin l ne B om t n a l me cu io f or th 4 po ti n. S d mide rea ts t y l ami soqu ol N cleoph l a t ty at th isoqu l n l po t i h wn by the od m d proces a w ll by comb n t f s qui ol e h rg n m t ll c c mpo d to gi l sub ti t ted d ri tives a d by th e ha ed e t ty f lhat soqu l e t d pl em t p oc e

1 Chl r oqu n lines ha e been obtained by diazoti ation of 1 ami oquinolines in concentrated hy d ochloric acid 1 Hyd xyi oquinoline or isocar b styr l exists in aque s l t on almost entirely in th 1-oxo form (X) Other hydroxyi oquin l ne d iate littl fr m the normal beh ior of phe ols 1 Methyl oquinol ne and to a much le er degree 3-m thyli oqu noline p s ess ctive methyl g oups Quaternizatio enhances th s reacti ty



Isoqu nol n 1-carboxyl ac d (XII) h s been obt ined d ectly or by way of i qui line 1-car boxald hyde by ox d tion of 1 methyli qui oli (XI) The sam acid a essibl f m i quinol th ugh the Rei rt compou d (XIII) 3-Methyl oqu nol an b xid zed with elen um dio de fir t to o q noli e 3-carboxaldehyde and thence w th hydr g n per de to i oqui line 3- c rbo ylic cid Oth r o qui line rboxyli acids ail ble hyd olysi pr du ts from the cor e p nding ia ders ti es all of wh ch can b bta ned by nt acti n f the b om soqu oli es w th cup ou cyan de Isoquinoline-1 car b xyl a ds e readily d ca bo ylated





W th om x pt n th react o f oq ol e h n l g u unte p rts i the eact f qu l e [W J CE]

B bliog phy R Adam (ed) *O g c Re c ti* l 6 1951 R C Elderfield (ed) *Het cycl c C mp d* 1 4 1952.

Isostasy

A theory f hydr tat q libr m in th rio s p rt f the arth s c u t Many c e t t now i dge th the ry o well c fi m d to con de ed ba l w f ge l gy B F H well Jr n 1959 tated it in s h xpl c t term a " ll

large land masses on the earth's surface tend to sink or rise so that given time for readjustment to occur their masses are hydrostatically supported from below except where local stresses are acting to upset equilibrium. *See* TERRESTRIAL GRAVITATION; *see also* EARTH. [C V C]

Bibliography: W. A. Heiskanen and F. A. Vening Meinesz, *The Earth and Its Gravity Field*, 1958; B. F. Howell, Jr., *Introduction to Geophysics*, 1959.

Isotach

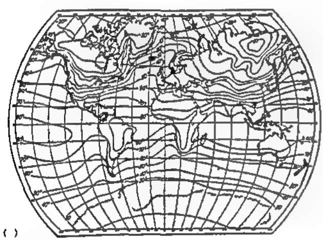
A line along which the speed of the wind is constant. Isotachs are customarily represented on surfaces of constant elevation or atmospheric pressure or in vertical cross sections. The closeness of spacing of the isotachs is indicative of the intensity of the wind shear on such surfaces. In the region of a jet stream the isotachs are approximately parallel to the streamlines of wind direction and are closely spaced on either side of a core of maximum speed. The term isovel is used synonymously with the term isotach. *See* JET STREAM; WIND. [F S]

Isothermal chart

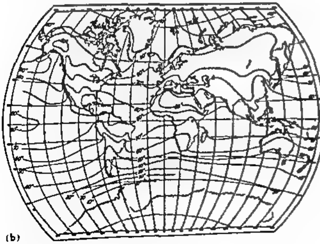
A map showing the distribution of air temperature (or sometimes sea surface or soil temperature) over a portion of the earth's surface or at some level in the atmosphere. On it isotherms are lines connecting places of equal temperature. The temperatures thus displayed may all refer to the same instant, may be averages for a day, month, season, or year, or may be the hottest or coldest temperatures reported during some interval.

Maps of mean monthly or mean annual temperature for continents, hemispheres, or the world sometimes show values reduced to sea level to eliminate the effect of elevation in decreasing average temperature by about 3.3F°/1000 ft. Such adjusted or sea level maps represent the effects of latitude, continents, and oceans in modifying temperature, but they conceal the effect of mountains and highlands on temperature distributions. The first isothermal chart, prepared by Alexander von Humboldt in 1817 for low and middle latitudes of the Northern Hemisphere, was the first use of isopleth methods to show the geographic distribution of a quantity other than elevation.

These maps are now varied in type and use. Isothermal charts are drawn daily in major weather forecasting centers; 5-day, 2-week, and monthly charts are used regularly in long-range forecasting; mean monthly and mean annual charts are compiled and published by most national weather services and are presented in standard books on, for example, climate, geography, and agriculture. *See* AIR TEMPERATURE; TEMPERATURE INVERSION. [A C]



(a)



(b)

World sea level isothermal charts. (a) January. (b) July. (After H. R. Byers, *General Meteorology*, McGraw-Hill, 1944)

Isothermal process

A frictionless expansion or contraction process accompanied by heat addition or removal from the system at a rate just adequate to maintain a constant temperature of the gas while the process is going on.

Because the internal energy of an ideal gas is a function of the temperature alone and because the temperature remains constant in this process, the internal energy stored in the system also remains constant.

In an isothermal expansion process the heat added to the system is precisely equal to the work done by the isothermal expansion, for there is no change in the stored energy of the system

$$Q_T = W + U_2 - U_1 = W = \int_1^2 P\,dV$$

where Q_T is the heat transferred at constant temperature T, W is work, U is internal energy, and V is volume. But from the perfect gas law

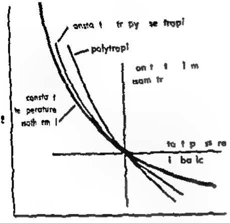
$$PV = mRT = \text{Constant} = C \quad \text{and} \quad P = C/V$$

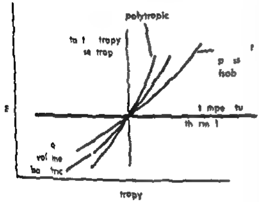
where P is absolute pressure, m is mass, and R is the gas constant. Thus

$$Q_T = \int_1^2 P\,dV = C\int_1^2 \frac{dV}{V} = mRT \ln\frac{V_2}{V_1}$$

$$= mRT \ln\frac{P_1}{P_2} = mT(s_2 - s_1)$$

where s is entropy. The isothermal reversible com-





soth rm l ess mp d t oth th rm dy m rocesse

p ess on p on p is omp ed to other de l g s p oces es th d gr m S e THERMO-DYNAMIC PROCESSES [J B]

Isotone

O I t o m toms which di play c n tant d ff n e $A - Z$ betwe their m n m be A nd th atom numb r Z Th s d pite d ff r es n th total n mber of n le cont t nent th umbe s f neut o n th nucl of sot nes th m The n mb s f naturally oc rri g ot es p id u f le id nce ncern ing th tab lity f m t cul r n ut n config a t F mple the rel tr ly l ge n mb r (x d en r sp t ly) of n turally ccur ring 50 and 8 n t n s t s ggest that th se nu l fig rati n espec lly table On th the h d from th f ct th t m t at ms with odd n mbers f utr e an t ne n y cl de th t dd n ut n co figu ti e l t ly u t bl S NUCLEAR STRUCTURE [H E D]

Isotope

On f tw mo t m h g the same t mi numbe Z b t d ff e t m n mbe A Th nucle f sot pes ta n d nt l mbe l p t n but d fferent number of neutrons Thus although they differ in ma s i otope belo to the ame chem c l l me t For mo t elements both stable and ad oacti e isot pes are known the latte how e er unless ccurri g naturally are di cu s d el e wh re See RADIOISOTOPE

The occ rrence and deg of i otopy among the 83 elements that are fo nd n nature in sign ficant am unts ha e been ascerta ned by mean f ma s pect omet r studi (s e MASS SPECTROSCOPE) Ti ($Z = 50$) for example po e es 10 stable isotope ($A = 112$, 114 115 116 117 118 119 120 122 and 1 4) a larger number th n any other lem nt On the oth r hand 0 element po es n is top s ea h of these c ns ts of o e typ of atom nly Su h el m nt are s d to be ani otop c The rema ni g 62 elements po s i ot pe ranging in numb r from tw to ni Altogether 287 d fferent at m peci are found in appr ciabl quant tie in nature (ee Ilu t at n)

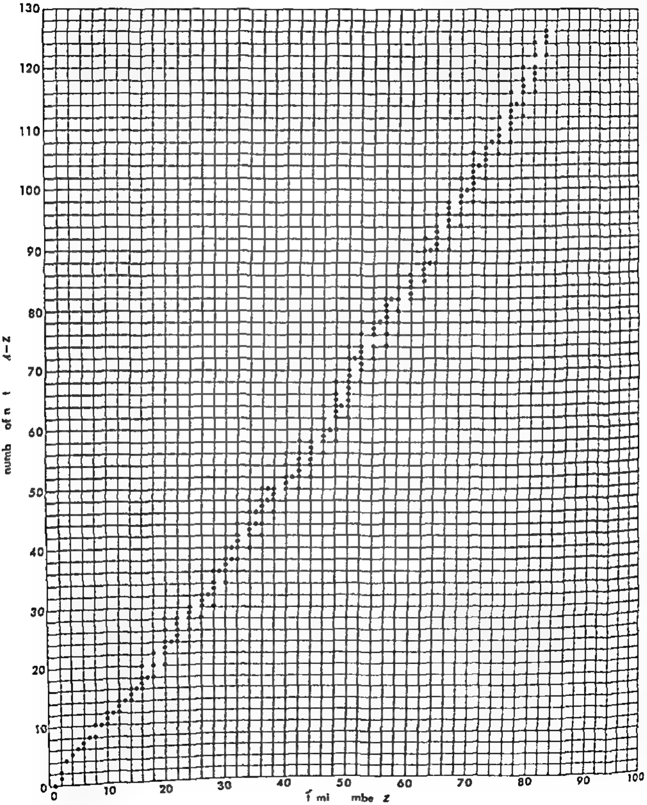
Nuclear stability Regul rit es in the table of naturally ccurring atom r veal ert in facts c n ce ni g nucle r f rces The 287 differ nt atomic spec e a e bd v ded as f llows 168 e en e n (e en n mber of proton and even number of n u t ons) 57 e en-odd 53 odd even a d 9 odd-odd The tat sti s d sclo e th pairi g t nden y f nuclear con tit ent a d establish that there is n sign fi ant differ nce in stabil ty betwee odd pro- t n d dd n utr n n figu tio Th e istence of a elati ly l rge numb r f isotopes pro ides e dence for a p rtic la ly tabl proton configura t on O th h si fo xampl th extra tability as oc at d w th the 50-prot e figur ti n (th t i tin) h s be n inf red See NUCLEAR STRUCTURE

Isotopic abundances M ch w rk ha b en don n determin ng elat e bund nces f isotope For many el m nts the relat e i top c bundances how no nat ral va t on O th ther hand the otopic on titut o of e al elements is t ongly d p dent up the h story of th r ple that be ng e tigated In th cases the aria ti n n top c con titut n can be ttr buted to c rt n atur l pro se nd the st dy f th vari ation pr id a p w rf l means of elucidating the pr c s e them l es d of ascertainin the p riod f tim in which th sample under in estiga n h hee subj ted to them Some detail of th type of tudy e now g en mme g with d u i n of bno m l i ot p c abu d nces ca ed by ad o t e dec y

Am g the t rally ccurring at m spe i s e a f w wh h are adi i e Th half l es (th e a erag t me nt rv l requ red f r one-h lf of a h t nderg d a t e d c y) are ery l ng b t k ow The mo t mportant m mbe of thi gro p e K Rb Th U a d U Th th e la t n med re t n f med by m i n of mplic t d q nce of α β d y } int tabl i t pe f le d (Pb Pb and Pb re pe ll ly) One m y the ef re by det mi g th p e nt m u ts f Th and ad geni Pb in g n omp te the age f the o e In an

analogous manner the age of uranium ores may be deduced K $^{\blacksquare}$ decays to either Ar^{40} (by β emission or K electron capture) or Ca ^{0} (by β emi sion) The K Ar^{40} decay is proving increasingly useful in the geochronology of potassium ores which are widely distributed in the earth s crust The Rb^{87} decay (to Sr^{87} by β emission) is also utilized in the dating of minerals In each of these cases the radioactive decay manifests itself as an altered from normal isotopic distribution in the daughter element *See* RADIOACTIVITY ROCK (AGE DETERMI NATION)

The other altered i otopic di tributions that are found in nature result from small differences in the physical and chemical properties of the isotopes of an element These differences lead to i otopic frac tionation (separation into different portions) chiefly via the proces es of diffusion evaporation



Ch t of stable isotop s

and chem c l excha g The f t nations produ ed by these p oce es a e mo t p onounced am g the lighte l m t where the perc ntag m d ff between isot pes e la ge

Normal hyd ogen con t f H (99 985%) and H (0015%) Th e t rd arily l g percent age ma d ffe en bet een the otopes re lts m n tu l fr t t on th t a e m ch l rger than f any oth eleme t The tw stable i topes of arbon ha th appr x m te bundance rat o C^{12}/C^{13} = 89 3 b t ma y nat ral mples d pl y l ge d f qu tly e plicable de t ns f m th s val e S m l ly s gnific nt riat ns hav been fou d in th O /O and S /S abund ce rati s. I e tigat s f thi typ dema d exceptio lly car ful (hem l) ampl p ep ati and p ec (m pe t ometri) isot p c a ly es. Th r ult are of great v l e t geophy ici t a d geoch m ts n u d tand ng the r le pl yed m n tu e by the pr esses wh ch lead to the fra ti nat of sotopes. Se GEOCHE ISTRY GEOPHYSICS

Use of separated isotopes Ce t in is top p ess pec lia p operti e not po ss d by othe isot p f th el ment. I c es whe e th pr perty i ffic tly s ght aft the top in q e ti n h bee epa at d from ts f llow i whole sale am unts. Fo nst ce be au of the effi y hea y hyd gen (H) i m de ti g n tr ns i n cle r t la g qua tit f H (n the rm f heavy wat r) h e been i lated from H th mp rt nt xampl th s pa t n f e l w tr n fi le U^{235} f m the m ch mor bu dant U Sep at d s top s ar a lable m t el m ts nd make p s bl th u q o l tudy f otop c effects a oppo ed t elemen al eff ts. S Is TOPE SEPARATION (STABLE ISOTOPES)

Th f m ny b ochem cal d othe rea s an b x m ed by nt d i g t tag bnorm l m xtu e of s t pes d e am ning at s bseque t t e the top c e n t t t f the el m nt o cerned Th tr r techn qu ut lizes d a tive t pes wh e th y a il bl but n u t ble d ti i top e i ts f e th n tr gen yg T a work i l i g th tw m t m t be d e with st bl t p m t re hich ha be n r ched i n m c nst tu nt S TRACER RADIOACTIVE.

Atomic weight A k wl dge f th ma a d b s d n e f each of the t p f el ment perm t the lc lat f t a ge at mi ma Exp es ed n the h m al le th s the h m l t m w ght. F ll t p eleme t (wh h any ert ty i t p c n st tuti d appe s) and f ma y i ot p c eleme ts a w ll th phy al app ch yield m ur te al es f r th at m w ght th n d th t d ti nal h m l method S ATOMIC WEIGHT

[H E D]

Bibl g phy F W A t n *Mas Spe t nd Isot pe* 1942 *P d g I t ti al Sympo I t p S pa ation* 1958

Isotope dilution techniques

The i troducti of rad tope i to stable i otopes f an element in der t make v lume m s and age me sureme ts f the elem nt The technique may be t b de cribed by ing imple example If knowledge f the t t l amo t of wa ter e ent in a contai er i de ired a mall amount of l bel d water D O or T O is added t the H_2O in the ntai er F r the purpo e of the m urement this am nt an be con dered to be 100% After the lab l d d uteri m or tritium is completely m xed with the w ter n the con t ner a s mple of the m xture f unit volume p rhap l m s rem ed and the am unt of labeled w ter in it determined If thi am unt is f und t be a% the the t tal m unt f water in th c ta ne will be 100/a

I the applic tion th m s f an elem nt may b det rm ned In th s a e th radioi otope is i trod ced and m xed sample is w thd awn a d b th the mount of rad is tope and the mo nt f t ble ch mi l pre are m a red The rat o f these tw m unts lled the cific acti ity an be e p essed a % d e/mg For ex ample od um 24 is admi tered t a pati nt and the pec fic ct vity of sod um in the blood (the am unt of labeled dium d ided by the am nt f stable sod um) determ ed Thi permits meas eme t of the total amount of excha ge ble so d m with n the body

All i tope dil t n t ch ique may be c n s de ed to be n ext on of the e simple measureme ts A m re c mpartments r cont i ers are added to the ystem howev r th analysi bec mes i cre gly diffic lt F rthe m the ass mpti n of immed te a d mpl te m x ng will no l nger be al d De pite the e diffic lt es th underlyi g n ne ples e ide ti l with the mpl ne ol me a e and i t p d l ti n tech que e fou d a wide a g f appl t i med e b ol gy nd du t y

Is t pe dil ti n is ft n u ed i n lyt al ch m i t y a es wh e a q ant tati e xtr ct of the s bst e to be ayed is diffi ult A mall q an t ty f lab l d subst dd d t th ample b fo e ep ti n and a aly i The xtr tio t th n a ri d t w th ut ega d to c mpl te es a d n rb tr ry mple s emo ed f a aly f the chemi al sub ta e a d f th labeled sub t nc F m th f the in tial a d fi l t ty the chem al a ay may b corrected t gi e th rre t mo t f chem c l i the ampl b f re xt a t n

Isotop dil t n te h iques h e al o f und n a n ppl ti s in g ol gy He e th y are u ed t d t rm the ab nd n a d d tribut n f t a e c tit ts pe lly n meteo te and t m ke g l g al ag det rm ti ns f r ex m pl th d t mi t n f th ag f a m a by the p t m g n m thod use Ar sp ke to d t mi e the r d og nic Ar the ample The A a dec y p d i l K reta ed w th n the

mica In these applications mass spectrometers are used to make the sample analysis *See* ROCK (AGE DETERMINATION) [G L B]

Isotope separation (stable isotopes)

Many chemical elements always occur in nature as a mixture of several isotopes The isotopes of any given element have identical chemical properties but there are slight differences in their physical properties because of the differences in mass of the individual isotopes (*see* ISOTOPE) Thus it is possible to separate physically the isotopes of an element to produce material of isotopic composition different from that which occurs in nature Although these separation processes are all quite difficult and expensive to carry out they are not inherently different from the usual operations employed in the chemical process industries

The separation of isotopes is particularly important in the nuclear energy field because individual isotopes may have completely different nuclear properties For example uranium 235 is used as a fuel for nuclear chain reactors heavy water (deuterium oxide) is used as a neutron moderator in nuclear chain reactors and deuterium gas is a possible fuel for thermonuclear reactors Separated isotopes are also used widely for research on the structure and properties of the nucleus

The process which is best suited for separating the isotopes of a given element depends upon the mass of the element and the quantity of separated material which is desired Research quantities of separated isotopes are best prepared by electromagnetic separation in a mass spectrometer For example gram quantities of many separated isotopes have been prepared at the Oak Ridge National Laboratory using the large electromagnetic separators which were built during World War II The electromagnetic process has the advantage that a fairly complete separation of two isotopes can be obtained in one operation

When moderate quantities of a separated isotope are desired thermal diffusion may be used Although thermal diffusion requires a large energy input this is more than offset by the simplicity of the equipment absence of moving parts and high separation obtained in a small volume

In the large scale separation of stable isotopes the best processes are those which have the highest thermodynamic efficiencies Reversible processes involving distillation and chemical exchange are best for separating the light isotopes such as deuterium For heavy isotopes such as those of uranium however no appreciable separation is obtained by the reversible processes and some type of irreversible process such as gaseous diffusion must be used Although reversible processes have in general higher efficiencies than irreversible ones the absolute efficiency of any isotope separation process is very small

Gaseous diffusion This process has turned out to be the most economical for the separation of the isotopes of uranium It is based on the fact that in a mixture of two gases of different molecular weights molecules of the lighter gas will on the average be traveling at higher velocities than those of the heavier gas If there is a porous barrier with holes just large enough to permit passage of the individual molecules but without permitting bulk flow of the gas as a whole the probability of a gas molecule passing through the barrier will be directly proportional to its velocity From kinetic theory it can be shown that the velocity of a gas molecule is inversely proportional to the square root of its molecular weight so that the efficiency of gaseous diffusion will depend on the ratio of the square roots of the molecular weights of the two gases present *See* DIFFUSION IN GASES AND LIQUIDS KINETIC THEORY OF MATTER

The only uranium compound which is a gas at a reasonable temperature and pressure is uranium hexafluoride UF_6 The two isotopes to be separated are $U^{235}F_6$ and $U^{238}F_6$ and the efficiency of separation depends on the quantity

$$\sqrt{U^{238}F_6/U^{235}F_6} = 1.0043$$

Since this number is close to unity the separation is very small in any one step of the process

The separation of the isotopes of uranium in the United States is carried out in three plants operated for the Atomic Energy Commission which are located at Oak Ridge Tenn Paducah Ky and Portsmouth Ohio In each of these installations natural uranium containing 0 71% U^{235} and the balance U^{238} in the form of UF_6 gas is separated into an enriched uranium product containing more than 90% U^{235} and a waste containing about 0 3% U^{235} The British have a gaseous diffusion plant at Capenhurst and the Soviet Union has facilities at an undisclosed location

The success of the gaseous diffusion process is dependent on the performance of the single diffusion stage In each stage UF_6 gas is compressed passed through a cooler to remove the heat of compression and then admitted to the vessel containing the porous barrier (Fig 1) About half the gas entering the vessel diffuses through the barrier and passes to the next higher stage This diffused gas contains slightly more of the U^{235} isotope The undiffused gas is slightly depleted in the U^{235} isotope and passes to the next lower stage

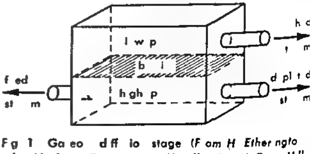


Fig 1 Gaseous diffusion stage (From H Etherington ed Nuclear Engineering Handbook McGraw Hill 1958)

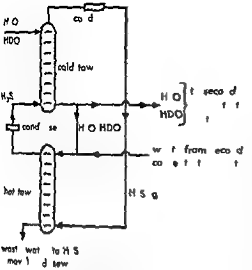


Fig 2 Dual te ture H₂S-HDO cha g Th d prod ct a m xtu of H O HDO a d D O th el the b d f D O o g the l t st g o R St ph f t od ct to N l E g 2d d McG w-Hill 1958)

Several thousand d d al stages are required to bring about the necessary overall change in composition. The combination of stages is known as a cascade, and the cascade which brings about the separation with the least work is known as an ideal cascade. The size of the stages varies tremendously; the feed, using the natural uranium, is to the stage where the largest and the final product stages the smallest.

Nickel-clad piping and process equipment are used to handle the UF_6 gas. Thousands of pumps and control instruments are required. The electric power requirement of the gaseous diffusion process is large, approximately 10% of the electric power output of the United States has been required to operate the three diffusion plants.

The gaseous diffusion process was originally designed as a means of producing highly enriched uranium for atomic bombs. At present much of the enriched uranium produced by gaseous diffusion is used as fuel for nuclear reactors.

Chemical exchange The chemical exchange process has proved to be the most efficient for separating isotopes of the lighter elements. The process is based on the fact that if equilibrium is established between, for example, a gas and a liquid phase, the composition of the isotopes will be different in the two phases. Thus if hydrogen gas is brought into equilibrium with water, it is found that the ratio of heavy hydrogen (deuterium) to light hydrogen is several times greater in the water than in the hydrogen gas. By repeating the process in a suitable cascade, it is possible to effect a substantial separation of the isotopes with a relatively small number of stages.

The chief use of chemical exchange is in the large-scale production of heavy water. A dual temperature exchange reaction between water which contains HDO and D_2O molecules as well as H_2O molecules and hydrogen sulfide (H_2S) gas for the primary separation of heavy water is used at the Savannah River plant. The separation is carried out in a series of hot towers operating at the boiling point and cold towers operating at room temperature (Fig 2). In each tower liquid water passes downward countercurrent to the rising H_2S gas. The relative distribution of heavy and light water is affected by temperature and the success of the process is determined by the difference between the concentrations in the hot and the cold towers.

Chemical exchange has also been used for the large-scale separation of other isotopes. For example the isotopes of boron have been separated by fractional distillation of the boron trifluoride–dimethyl ether complex.

Distillation The separation of isotopes by distillation is much less efficient than separation by other methods. Distillation was used during World War II to produce heavy water, but the cost was high and the plants are no longer in existence. The only present large-scale use of distillation is at Savannah River, where fractional distillation is used to concentrate the product from the dual temperature process (12–16% D_2O) up to 95–98% D_2O. See DISTILLATION.

Electrolysis Electrolysis of water is the oldest large-scale method of producing heavy water. Under favorable conditions the ratio of hydrogen to deuterium in the gas leaving a cell in which water is electrolyzed is 8 times the ratio of these isotopes in the liquid. In spite of this high degree of separation, electrolysis can be used only where electricity is very cheap, as in Norway, because of the large power consumption per pound of D_2O produced. Electrolysis is used in the United States only as a finishing step to concentrate the final product specification.

Electromagnetic process Electromagnetic separation was the method which was first used to prove the existence of isotopes. The mass spectrometer and mass spectrograph are still widely used by physicists and chemists (see MASS SPECTROSCOPE). In the electromagnetic process a vapor of the material to be analyzed are ionized, accelerated in an electric field and enter a magnetic field which causes the ions to be bent in a circular path (Fig 3). Since the light ions have less momentum than the heavy ions, they will be bent through a circle of smaller radius, and the two isotopes can be separated by placing collectors at the proper location.

During World War II a large electromagnetic separation plant was built at Oak Ridge to separate the isotopes of uranium. The large mass spectrometers used there were referred to by the code name Calutron, a contraction of California University

cyclotron The first kilogram quantities of U^{235} were produced in 1944 With the completion of the gaseous diffusion plant at Oak Ridge the electro magnetic process was found to be uneconomical and was abandoned in 1946 However some of the equipment is still being used to produce gram quantities of separated isotopes for research purposes

Thermal diffusion The separation of isotopes by thermal diffusion is based on the fact that when a temperature gradient is established in a mixture of uniform composition one component will concentrate near the hot region and the other near the cold region Thermal diffusion is carried out in the annular space between two vertical concentric pipes the inner one heated and the outer one cooled Because of thermal convection of the fluid there is a countercurrent flow which greatly increases the separation obtained in simple thermal diffusion and makes possible substantial separations in a reasonable column height

Thermal diffusion has been used to separate small quantities of isotopes for research purposes In 1944 a plant was built at Oak Ridge to separate the isotopes of uranium by thermal diffusion However the steam consumption was very large and the plant was dismantled when the gaseous diffusion facilities were completed

Centrifugation The use of a centrifuge to separate isotopes has one major advantage namely that the separation depends only on the difference in masses of the two isotopes and not on the ratio of their masses Thus it is no more difficult to separate the isotopes of uranium than those of the light elements A disadvantage of the centrifuge method is that a very high speed of rotation is required to obtain any substantial separation in a single unit

A centrifuge pilot plant was built during World War II but further work on the process was discontinued because of engineering problems involved in the operation of high speed rotors the low capacity of the individual machines and the large power input required to overcome friction *See* CENTRIFUGATION

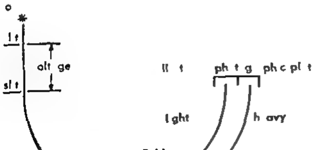


Fig 3 Diagram of mass spectrometer or Calutron (From R Stephenson Introduction to Nuclear Engineering 2d ed McGraw Hill 1958)

Nozzle process Isotopes can be separated by allowing a gaseous compound to exhaust through a properly shaped nozzle Preliminary calculations indicate that this relatively new method may be competitive with gaseous diffusion for separating the isotopes of uranium *See* RADIOISOTOPE PRODUCTION *see also* DEUTERIUM HEAVY WATER NUCLEAR FUELS [R M SN]

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Isotope shift

A displacement of spectral lines which come from the different isotopes of an element This shift in wavelength is caused mainly by differences in nuclear masses and differences in nuclear volumes The first effect predominates in the lightest ele-

Isotope shifts in the green line of mercury Dashed lines indicate the hyperfine structure components of the isotopes having odd mass numbers

ments but becomes negligible for atomic numbers greater than about 40 The mass effect in 1 electron atoms results from the variation of the reduced mass $mA/(m+A)$ where m is the electron mass and A is the nuclear mass and was important in establishing the Bohr theory (*see* ATOMIC STRUCTURE AND SPECTRA RYDBERG CONSTANT) The shift of the first line of the Balmer series between hydrogen and deuterium is 1 325A and this led to the discovery of deuterium The volume effect is important for heavy elements and gives information about nuclear structure Deviations from the theoretical volume effect allow an evaluation of nuclear quadrupole moments and nuclear shape A typical volume effect is shown in the illustration Though the lines from the isotopes with even mass numbers are seen to be almost equally spaced the lines for the odd ones do not lie even approximately halfway between [F A J]

Isotopic spin

A quantum mechanical variable introduced for convenience in interpreting nuclear reactions and hyperon decays

In the quantum mechanics of atomic nuclei it is sometimes convenient to regard the proton and the neutron as two different states of the same particle called the nucleon The concept is useful as a means of giving expression to the apparent

charge independence of strong nuclear forces that is, the fact that proton-proton, proton-neutron, and neutron-neutron interactions are apparently the same. See NUCLEAR ...

A variable T_3 is introduced which has the value $+\frac{1}{2}$ for the proton and $-\frac{1}{2}$ for the neutron, so that the charge of a nucleon is $|e|(\frac{1}{2} + T_3)$, $|e|$ being the absolute value of the charge of the electron or proton. The isospin kind of exchange forces which play a role in nuclear theory thus find simple expression by treating T_3 like a component of a quantity formally resembling an angular momentum vector T for each nucleon, which is called the isotopic spin or isospin. The name comes from the formal analogy to spin and is somewhat unfortunate, since it does not have anything to do with actual spin. Nevertheless, this name is so well established by usage that there is little chance that it will be changed.

Individual energy levels of composite nuclei are assigned a quantum number T, which also represents the magnitude of the vector resultant of the individual isotopic spins of the constituent nucleons. The resultant T_3 for all the nucleons in a nucleus containing A nucleons, of which Z are protons and $(A - Z)$ are neutrons, is

$$T_3 = \tfrac{1}{2}Z - \tfrac{1}{2}(A - Z) = Z - \tfrac{1}{2}A$$

Because of the charge independence of the strong nuclear forces, the energy levels will depend strongly on T but only slightly on T_3. This conclusion is in accord with observation, which shows close correspondences between the energy levels of isobaric nuclei.

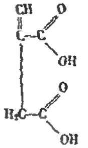
In a similar manner, it has been found useful to designate the three kinds of pi-meson as corresponding to the values $T_3 = +1, 0, -1$ of a single type of elementary particle, the pion, where the values $T_3 = +1, 0, -1$ correspond to positive, neutral, and negative pions, respectively. This affords a convenient way of treating the charge independence of the strong interaction of pions with nucleons. See ELEMENTARY PARTICLE; HYPERON; MESON; NUCLEAR STRUCTURE; SELECTION RULES (PHYSICS); SYMMETRY LAWS (PHYSICS). [E.L.C.]

Isotropy (physics)

A body is said to be isotropic if its physical properties are independent upon the direction in which they are measured. A body displaying isotropy holds only one ... one direction ... Most but not all liquids and aggregates made up of many small crystals randomly oriented display all the properties ... Depending on their ... crystals may or may not be isotropic with respect to ... properties. For example, ... with respect to ... be true ... with respect to electric conductivity but not with respect to deformability. See ANISOTROPY; ELASTICITY. [D.T.]

Itaconic acid

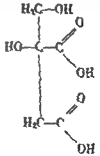
An organic acid, methylene succinic acid, which decomposes at 165°C, having the following structural formula



Fermentation is a potential microbiological large-scale method for production of this unsaturated branched-chain dicarboxylic acid as a raw material for certain plastics with special properties (see FERMENTATION). A medium consisting of commercial grade glucose 15–20% and inorganic salts is adjusted with hydrochloric acid to pH 1.8–2.0. The pH of the medium is critical. The medium is inoculated with spores or mycelium of a selected strain of the filamentous phycomycetous fungus, *Aspergillus terreus*, is aerated or agitated in stainless steel fermentors at 35°C for 2.5 days. Itaconic acid can also be produced by the surface or tray process. The yield is approximately 40% of the sugar consumed. The free acid is crystallized from the filtered fermentation liquor after vacuum concentration and cooling. [J.W.F.]

Itatartaric acid

An organic acid, a dihydroxyitaconic acid, which has been produced experimentally by fermentation (see FERMENTATION). Its structural formula is



The compound is formed as a minor product, 5.8% of the total acidity produced from an itaconic acid-producing strain of *Aspergillus niger* (see ITACONIC ACID). The strain is an ultraviolet-induced mutant (see MUTATION). Itatartaric acid and itaconic acid are produced in approximately equal quantities. See INDUSTRIAL MICROBIOLOGY. [J.W.F.]

Itch

A pattern of cutaneous sensation allied to pain. A variety of different stimuli—mechanical, electrical, chemical, and thermal—may produce it. The most

vivid and persistent itching is associated with pathological skin conditions (prurigo) and with the irritant action of itch powder, the spicules of the plant cowhage (cowitch).

The most convincing evidence that itch derives from the operation of the same nervous mechanism as that responsible for pain comes from experiments on human skin. In these experiments a brief train of high-voltage sparks imparted to the skin at a rate of five or more per second, each too weak to elicit any sensation singly, may evoke the itching sensation. The same stimuli at higher intensity yield pain. The presumption is that itch is associated with a slow but enduring succession of low-frequency impulses in the cutaneous nerve fibers leading to the central nervous system from that portion of the skin. Pain of a stronger and more disagreeable quality results from nervous discharges of higher frequency.

In skin rendered irritable by disease or inflammation, itching may sometimes be evoked by simply touching or stroking it mechanically. Temperature changes may produce itch under some conditions. However aroused, the itch sensation is a powerful stimulator of action, leading promptly to scratching or some other device to break up the persistent steady pattern of nervous impulses underlying it. *See* PAIN, CUTANEOUS. [F.A.G.]

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Ixodides

A suborder of the Acarina, class Arachnida, comprising the ticks. Ticks differ from mites, their nearest relatives, in their larger size and in having a pair of breathing pores, or spiracles, behind the third or fourth pair of legs. They have a gnathosoma (or so-called head or capitulum) which consists of a base (basis capituli), a pair of palps, and a rigid, elongated, ventrally toothed hypostome which anchors the parasite to its host. They also have a pair of protrusible cutting organs, or chelicerae, which permit the insertion of the hypostome. The stages in the life cycle are egg, larva, nymph, and adult. The larvae have three pairs of legs, nymphs and adults four. The 600 or so known species are all blood-sucking external parasites of vertebrates, including amphibians, reptiles, birds, and mammals.

Ticks are divided into three families: Argasidae, Ixodidae, and Nuttalliellidae. The last contains but one exceedingly rare African species, *Nuttalliella namaqua*, which is morphologically intermediate between the Argasidae and the Ixodidae. It is of no known importance either medically or economically.

Argasidae. Argasids, or the soft ticks, differ greatly from ixodids in that the sexes are similar; the integument of adults and nymphs is leathery and wrinkled; there is no dorsal plate or scutum; the gnathosoma is ventral in adults and nymphs but anterior in larvae; and the spiracles are small and anterior to the hindlegs (Fig. 1). These ticks frequent nests, dens, and resting places of their hosts. Adults feed intermittently and eggs are laid a few at a time in niches where the female seeks shelter. Larvae feed for a few minutes to several days, then detach and transform to nymphs which feed and molt several times before transforming to adults. Nymphs and adults are notably resistant to starvation; some are known to live 10 years or longer without feeding.

Fig. 1. Argasid tick, Ornithodoros coriaceus, about 8 times natural size.

The family contains about 85 species, with 20 in the genus *Argas* and 60 in *Ornithodoros*. Several are of medical or veterinary importance. *Argas persicus* (Oken), the fowl tick, is a serious pest of poultry throughout most of the warmer and drier regions of the world. Nearly everywhere it occurs, it carries fowl spirochetosis, a disease with a high mortality rate. Larvae and nymphs of *Otobius megnini*, the spinose ear tick, feed deep in the ears of domesticated animals in many semiarid regions. Heavy infestations cause intense irritation which leads to unthriftiness and sometimes to death. The life history is unusual because adults do not feed. *Ornithodoros moubata* (Murray) transmits relapsing fever in East, Central, and South Africa. It is a highly domestic parasite and man is probably the chief host. *O. turicata* (Dugès), *O. hermsi* (Wheeler, Herms, and Meyer), *O. talaje* (Guérin-Méneville), and *O. rudis* (Karsch) are important vectors of relapsing fever in the Western Hemisphere, as is *O. tholozani* (Laboulbène and Mégnin) in Asia. The bites of most species that attack man produce local and systemic reactions; the bites of some species, especially *O. coriaceus* (Koch) of California and Mexico, are extremely venomous.

Ixodidae. In contrast to argasids, Ixodidae have a scutum covering most of the dorsal surface of the

Fg 2 I odd h k D m d n I m l bout 15 hm otu l

m le b t only the anter porti n f females nymphs, and l rv e (F g 2) They a e k wn a th h d tick Th are thu m kedly d s- m l r The gn th oma xtend nte ly and the larg p le a e po t r t the h dleg I te d f f eq nti g nest pl ces these tick are lly m or les r domly d tril ted th gho t th h ts en o m nt Larva nymph a d ad lts fe d b t n e d r l days are equ ed f ngorg m nt The mmat e t g f most pec es d p t th gr d f m lti g but thos f th g n B phlus and a few thers m lt the h t The f m le lay a ma s c nt g p t 10 000 o m gg The l fe cycl s ally mpl ted i o l years

The f mily i f about 11 well d f ed g n ra th 500 pe es Ma y speci tr mit d ea e agents to ma and animals included are iruses r k tt ae l acteri pr to oa a d to in Trans miss on s by b te r by conta t with crushed tick tis ues o e creme t Vir s dis a es f man in lude Colo d tick fe er of w stern Un ted States tra s- m tted by *De mace tor a der on* St les and Rus- s n sp ing summer encephal tis and related dis- e Eu pe and Asia tr nsmitt d by *Ixodes pe sulcat s* Sch lz S m imp rtant r ckettsi l d e es f man are R ky M nt in spotted fe er w d ly d t buted in the W tern H mi phe e f wh ch *D nd rso i D Va bil s* (Say) *Rhipice phalus s nguineus* (Lat ille) d *Amblyomma aj nense* (F br ius) a e important vecto bout nn u fe r d elated d ea of the Med terra ea reg on nd Afr a t ansmitted by *R sa gui eus* and some other spec a d Q fever the ag t f wh ch although oc urr ng in many tick thr ugh t th w ld not ommonly t ansmitted dir ctly by them Tularem a (abb t fe er) is a bacte al d e s t a smitted by ev ral species f ticks in the N rth rn Hemi phe e Tick paralys s belie d t be t n au d oc urs in many pa t f the w rld d prod ced by *se eral species of* ti ks during the feed ng p ess.

The ume us t k b ne d s a es of an m ls e vast econ mic l sses especially n t opical a d ubtrop c l reg s Examples a babesiasi a m t zoan d eas caused by species of *Babes a* in cl d g *B b g mi* the ag t of the widely d tr b ted T xas attle f er wh ch t a smitted pr nc pally by sp ies f *B ophilus* East Coast fe e f Afr a n th r proto an d se, used by *Th l ria p* ts c rr ed by e eral sp ies f *Rh p eph lus* A d f m ca ry ng d e se, sev e al pec e ext mely important pest of m d an mal Heavy nf t t o of t ks prod ce r m i l estock and e en de th from l of blood alo *Se* articles pecific d s- *es s al o* ACARI A [G I K]

Jade

A name that may be ppl ed c rrectly to two d t n t m er l Th two t ue jades e j de t and phrit I add t va ety of other mine al are me rre tly called jade Idocr e i called Cal f rni j de dyed le te i called Mex c n j de and gr e gr l ite g net s lled Tr svaal t So th Af c n j de The m st widely d trib ted d a l t kn w tr m type i ephr te the le r l abl f the t Jad te the mo t pr u f gem m nes to the Ch ne e s much are a d m r expe rv

Nephrite Neph te n of the mph bole gr up f rock form g mi er l nd it c u s a ty of omb at of th m ne l t em l t d tr l te Tr m l te s c l m m gne m lum num l te whe e s n r pl c s th m g nes m in a t n l te Although ngle cry tal f the mph bol a fr g le b ca e of two d ec tn f easy le the m tely fibr s truc tu e of ph te make t x e d ly d rable It occu r et f l rs m stly f l w ten s ty l d med um d da k g e yell w bla k a d bl e-gr y N phrite h ha d es f 6–6½ on Moh c l a p cific g ty e r 2 95 d r f ct d es f 1 61–1 64 On th r f a t m t ph te gem st n h w a s ngle d x 1 61 N phr t occ th o ghou t the w ld importa t so ce cl de R ss N w Z l nd Al ka, e l pr n e of Ch n and n mb r of tates th western U ted St te *Se* AMPHI BOLE GEM

Jadeite Jade te th m re her hed f the two j d m al bee f th m i t n e l rs n d pl y It i b t kn w n the l ly i te e gr n col r res mbl g th t f m ald (ed by m ll m t f hr m c o id) I th qu l ty kno n mp ri l jad th m t l s t l t sem t p t Wh t gre nd wh te, l ght ed d h olet bl h let brown a d nge lo lso f u d J d te l h s two d t n of e y cl age, b t a mpa ble a d m fib o stru t e ates xc pt nal t ugh s Al though j de t h be f u d Cal forn a d C tem la, th l impo tant s f gem q l ty m t ri l es d c red th M g g eg f ppe B rma Th h d of j d t s 6½–7 it pec fi g ty i pp m t ly 3 34 d t ref ct i es a e r 1 66–1 68 f c tom i ly the l e 1 66 lly e

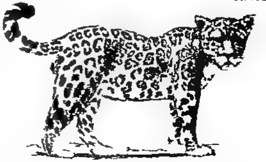
[R T L]

Jadeite

The name given to the mon clin c sod um alum num pyroxe e N Al $(SiO_3)_2$ J de te f rms green fi f ous cry tals that are col le in th n secti ns a d e h but the 87 pyro ene (110) cl avage Jade it is rar m tam ph n m ne l f und in some se pe tine masse as ociated with other den e m erals ch s l ws nit CaAl Si O (OH) gl u cophan g net and othe minerals ch a d p de t em l te serpentine nat ol (a zeol te) and chl it Beca se f the prese e of albite a d q rt or albite and neph li e mi er l pairs m ome j deite pecimens a d the o gh simil rity of the rock to the ecl g t t i th ught th t jad ite co r prese t high p e ur mod fi at n of al b te nd n pheline alb te + ephel n = 2 j de ite Th rea t o has bee prod ced n th labor t ry t 600 C nd 11 kilob rs p e sure or 900 C d at 12 kiloba s p s u e The react n albite = jadeite + qu rt cu s in the laborat y at 600 C t 7 k l b pr s o 900 C at 15 5 kil b rs p e su Attempts t synthe ze j d ite at lower pr ss e h e been n u ce sful Th mi eral s sociat s n th natural ccurrenc s of jad d ny the pr se ce f h gh tempe t es J de te c ld be th a d m m neral n the l w r r g n of the arth t Jade t the f w pl c s wh e t o s cl d Bu m Celebe Cent al Amer c J pa d S Be ito Co nty Calif n Jade te al ed a p ec o s to e f r c ry g *S e* GLAUCOPHANE PYROXENE *lso* HIGH PRESSURE PHENO IENA JADE [G W D]

Jaguar

A l g m ore *F lis n* f the f mily Fel d met m s c lled th Am an leopa d Th jagu r i f und f om P tag n a n thwa d t th Un ted



J g F l l gth t 79 in (E L P lm f Fi b k f N t l H st ry M G w-H ll 1949)

States border and rarely in Texas, Arizona, and New Mexico. The jaguar may attain a length of 7 ft and may weigh up to 225 lb. It is essentially a jungle cat; it exhibits great agility in spite of its size and is able to climb trees and to swim with facility. The jaguar has been known to kill and eat humans. It may eat almost any moderate-sized or large animal, including alligators, turtles, pigs, tapirs, horses, and cattle. Jaguars have beautiful valuable fur which is tawny above, white below, and regularly dotted with black spots; most of the spots on the back and sides are open rosettes. *See* CARNIVORA. [J.D.B.]

Jamming

Intentional generation of interfering signals by powerful transmitters as a countermeasure intended to block a communication or radar system or to impair its effectiveness appreciably. Radio broadcasts or radio messages can be jammed by beaming a more powerful signal on the same frequency at the area in which reception is to be impaired, using carefully selected noise modulation to give maximum impairment of intelligibility of reception. When stations on many different frequencies are to be jammed or when an enemy is changing frequencies to avoid jamming, the jamming transmitter is correspondingly changed in frequency or swept through a range of frequencies over and over again. Similar techniques are used at radar frequencies to jam early warning and gunfire control radar systems. *See* ELECTRONIC COUNTERMEASURES. [J.M.R.]

Japanning

The finishing of metal objects with a black baking varnish that consists primarily of a hard asphalt such as gilsonite. Japanning was widely used for metal finishes before the development of modern synthetic enamels. This use has largely disappeared because the same properties can be obtained with finishes based on synthetic resins that are resistant to heat and solvents and are available in a number of colors.

The term is sometimes applied to coatings obtained with Oriental lacquer made from the juice of a sumac tree. This also is no longer widely used. *See* LACQUER; VARNISH. [F.S.D.]

Jasper

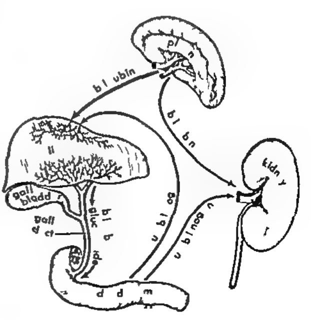
An opaque, impure type of massive fine-grained quartz that typically has a tile-red, dark brownish-red, brown, or brownish-yellow color. The color of the reddish varieties of jasper is caused by admixed finely divided hematite, and that of the brownish types by finely divided goethite. Jasper has been used since ancient times as an ornamental stone, chiefly for inlay work, and as a semiprecious gem material. Under the microscope jasper generally has a fine granular structure, but fairly large amounts of fibrous or spherulitic silica also may be present. *See* GEM; QUARTZ.

Jasper has a smooth conchoidal fracture with a dull luster. The specific gravity and hardness are variable depending upon particle size and the nature and amount of the impurities present; both values approach those of quartz. The color of jasper often is variegated in banded, spotted, or orbicular types. Heliotrope is a translucent greenish chalcedony containing spots or streaks of opaque red jasper, and jasp agate contains bands of chalcedonic silica alternating with jasper. Jaspilite is a metamorphic rock composed of alternating layers of jasper with black or red bands of hematite. [C.F.R.]

Jaundice

The yellow staining of the skin and mucous membranes associated with the accumulation of bile pigments in the blood plasma. Bile pigments are the normal result of the metabolism of blood pigments and are normally excreted from the blood into the bile by the liver. An increase in circulating bile pigments can therefore come about through increased breakdown of blood (hemolytic jaundice), through lack of patency of the bile ducts (obstructive jaundice), through inability or failure of the liver to clear the plasma (parenchymal jaundice), or through combinations of these. *See* GALLBLADDER; LIVER.

Metabolic pathway. A graphic representation of the pathway of bile pigment metabolism in the body is shown in the illustration. Metabolism of the hemoglobin from destroyed red blood cells is carried on in organs of the reticuloendothelial system, such as the spleen, and the resulting bilirubin is liberated to the plasma. The plasma then circulates through the liver, where the bilirubin is conjugated enzymatically with glucuronic acid and excreted in the bile. Bile travels through the bile ducts to the small intestine, whence a small amount of altered



Pathway of blood pigment metabolism.

bilirub n, termed r l lnog n m y b e b o bed into the pla ma. Ex es ■ destructi n of ed bl od cell will cau e accel r ted p odu ti ■ of bil rub n or l ad the ab l ty f the li er to em the pig ment f m the c rc lati n and produ ■ jaund ■ Blockage f the bil ducts will cause elevat on of pla.ma b'lirub n gl cu n d level b c u e f the inabil ty to di p se of thi mat r al i the u ual h n l. Damage t l r ell m y cau ele at on of the pl ma bilirubin o b l rub glocuronide o both, dep d g on th typ and s rity of liv r ll damage

Jaund e occ s whe the le el of the reulat mg p gm ts be m o h gh that they a e i ble in the kin a d m o memb n s whe e they re bo nd by a rea t n which has ot b en ident fied I the n rmal dult t tal b l rubin that in the to tal b'lirr b nd b lirub glucuronide level rar ly ex eed 0 8–1 0 mg/100 ml of pl m wh le j dic ally becomes is ble when total bil ru bin pp ches 1.5 mg Se BILIRUBIN

Hemolytic jaundice De truct n f red blood c lls in th orm l h m n adult p ce ds at a rate in h h bout 0 8% f the ci culati g hemoglob n broke d wn ea h day Thi c b incr d n stat s of x es i e hem ly i up to 10–1 fold w th ut o erta ng the remark ble bil ty of the l ver to l b l rub f m the pl ma E n thi r te f cl n g can be x eeded howev r in cert n m b d t tes i cl d ng ar o s h m lyt nemias hem l es lt ng f m in mp tible blood t ans f sev r therm l lectr c nj e n nt o duct n f h m lyt gent nto the bl od st e m S m7 j ndi e oc u s in p lmo ary f cti n

I fa t a d e pec ally p em t re infant th b'l t of th l er to jug te bil rubin with glucur n d is m ch les tha in dults appa tly be se of the l ck f u table nzymes Jau d appears n m ny i f nt h rtly aft b rth then d ppe r with n a few d y with de elopment of th ppr p iate zym tructu I the om m n e t t t al hepat dy f n t n th n *syme d fect* pp rently per i ts nto adult l f The m'aul j d c mp ny g eryth obl st fet l (Rh b b es) d t the b l ty f the inf t l li e t m tabol e the b l ubin esult g from m rkedly ace le at d hem ly is. S BLOOD C OLLS

Obstructive jaundice Th h ghest le l of t tal b l rub n r ce n ch b tru t e j u d m h h pla m lev ls m y r h 50–60 mg/100 ml, and the k may tak n ma k ble d p y ll w h Thi d t n m be br ught bo t thr gh a ty f m n l th inf t th m y be er ■ ldevel pm t f th b le d ct uch that o h n l f the fl w of b l ex st hil n the adult b tru t j d e mo t omm nly c ed f y imp t f a gll i n n the d is B gn nd m l gn it m r f th gall bl dd b l d cts p c e lymph odes d b l d i th l s f p t y a d l l d t tr

tu e may follow surgery or i flammation in the re gion A s m l ■ less e e e rever ible picture i seen as a hyper en iti ity esp n e t the adminis tration f some dr gs the m st common of which r chl rpr mazin and elated drugs and methyl test t rone In the un ommon benign di order known as idiopathic familial jaundice the e ap pears to b decrea ed ab lity to exc te conjug ted bil rub into the bil du ts gi ng ri e t a con stant elevat on in the plasma b lirul n glucu onide whi h is u ually q ite sl ght

Parenchymal jaundice A w de variety of dis e e e i ts in which part f th jau dice can be a ■ unted f by a tual damage to liver cells with nse juent dec e ■ in their abil ty to conjug te bilirub n and excrete the gluc r n de causing an le at n of both fr cti n ■ the plasma This group omp s s uch ondit ons a inflammations f the li er i cludi g viral hepat ti Weil s dis ea e syph l s par s tic nfestations and b ct ial nfect n to ic co d ti s in lud ng po s ning with a wide a ety of ■ gan c and inorg nic com pou d nd i a wide sense the to em s associ ated with ev re sy tem c di eases tum *rou co* dit n including primary hepat c t mo s a d tho e metast tic f m other org ns and other miscella n u c nd ti ns th e mo t c mm n of wh ch is on ge ti e heart failure Some of the e co ditio s ha e an added c mp nent of ob tru t e r hemo lyt c jaund ce which confus th p ct re f r th l ic an

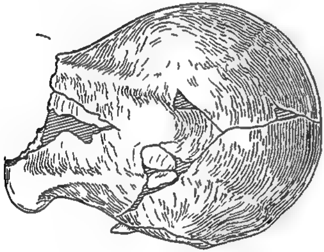
Symptomatology The app ara ce and symptom tol gy f subject suffe i g from j und ce ary f m a t a d pe d ng n the u d ly ng d e e process produci g the jau d e P tients w th hemolyt c jau dic fo m ta ce will ■ ually ha e n ccompany ng nem a th e w th bstruct ■ jaund c will c mm nly n te that thei tool are n t brown be a e of la k of b le p gme t (ch l c tool) whil bil rub n glu u de will appe th ur ne d cau e it to t rn dark P ti t w th mal gn n ies will demonst t the u u l s gn of weight los a d a m a wh le tho e with nfl mm t ry o d t ns will c mm nly h fever h lls d pro t at on See PIGMENTATION [R B H]

Java man

The most pr miti e know f rm of man and one f th ■ t d ti g *prob bly* from the late lowe a d e ly m ddl Plei t n corre ponding t the F r t I tergl c I and S nd Glacial phas s f th Northern H m ph The fir t pe im disc ed at *Tr n l in* t al Ja a by Euge e Dubois n 1890–1892, n ted of skull c p femu mandi ble f *gm nt* and few t eth (the l t n w s gned t angut n) D boi d cribed these un der th n me *P th c th opus e ctus* as th fi st e mple f ry *primit* man th wa m le i a thr p l g l d ry a d d bat Othe k ll p and jaw fragment we fo nd s oc ated with both th Djeti nd Trin l faun of

Java in 1936–1939 chiefly by G H R von Koenigs wald No implements are known from these beds The thigh bone indistingui hable from that of modern man indicates a fully developed posture for upright walking The brain case is extremely thick with a cranial capacity averaging about 850 cm (modern man 1450 cm³ gorilla 500 cm³)

l t al v w



d s l v w

Cran m of P th ca thropus e ctus ll aft von Ko n gswald (Courtesy Ca I tt t n of W h g t d i M F A hl y Mo tagu A I t ducti o to Phys cal A th pology 2d ed Cha les C Th mas 1951)

The tooth row is long the lower molars totaling 40 mm An exceptional feature is the pre ence of a dia tema (precanine gap) in the upper to th row related in anthropoid ape to the reception of the projecting lower canine thi feature has l een found in no other hominid including *Au strulo pithecus* However the canine teeth them el e are not projecting or nonhominid in nature *See* Fo SIL MAN [W W H]

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Jay

Any of everal maller members of the family Corvidae differing from other crows in maller ize and in more brilliant plumage Various pe-

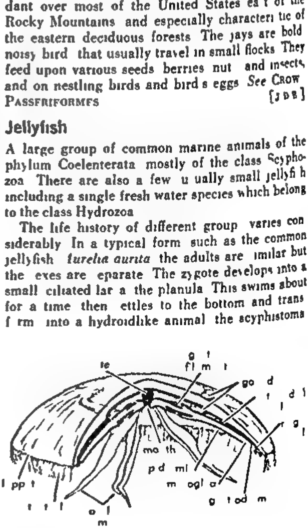
The bluejay (Cyanocitta cristata length 12½ in (F om E L Palmer F ldbook of N t ral H story Mc G aw H ll 1949)

cies occur in both North and tropical America and in the Palearctic Most common is the bluejay *Cyanocitta cristata* widely di tributed and abun dant over most of the United States ea t of the Rocky Mountains and especially characteri tic of the eastern deciduous forests The jays are bold noisy bird that usually travel in small flocks They feed upon various seeds berries nut and insects and on nestling birds and bird s eggs *See* CROW PASSERIFORMES [J D B]

Jellyfish

A large group of common marine animals of the phylum Coelenterata mostly of the class Scypho zoa There are also a few u ually small jellyfi h including a single fresh water species which belong to the class Hydrozoa

The life history of different group varies con siderably In a typical form such as the common jellyfish *Aurelia aurita* the adults are imilar but the exes are eparate The zygote develops into a small ciliated lar a the planula This swims about for a time then ettles to the bottom and trans f rm into a hydroidlike animal the scyphistoma



The jellyf h Au el a a ta d ag ammat c (Fr m T I St a d R I Us g al Zo logy 3d d McG aw-H ll 1957)

he l tt tt ı a length f b ut 12 mm a d th n nd goes pec l type of m lt pl tr er e ı res ltın a f c nected mall nmals c ll d phyra Thes ucerl ke anımal epa at om f e-s ımm ng (thus mplet ng he a e l tag of p oduct n) d tr sform nt the ad lt or xual t ge Mo t jell hes h a s m l ltern t f g n at ns m t ı esıs, a h tert t of the phyl m

J ll fi h s vary ı ız from G mus ½ ın ın d amet t the gıa t jelly *Cy a apıl lata*, ıth a dı k p to 7½ ft ro s te t cl 120 ft l g a d h l t M t jellyfi hes e m b mall r alth gh pe m s 3–4 ft cr ar k wn.

I color the j llyfi he h w w d a ge f m vrt llyn n t be t ful ıdesc t p tel Th r b stru t e mu h l k that of *Hyd a* (se Hydra) The m uth pe on the unde d f the mbr ll food ı s ızed by the oral arms d q ed by th t gıng lls o emat cy ts lo- c ted these rms d n the f ı ge f t ta le d th bell

Th f esh ate j llyfi h ha be rep ted o ly a few tımes a d f om wıd ly pa ted l calıtıe the U ıted St t s b t when fou d u f few d ın l ge mbers It the d appe c m plet ly d m y e r g ı be r c ded fr m that loc l ty Th lo m a d *G mus* c mmo al g the Ea t Coa t of the U ted St tes e hyd o- zo S Coele terata Metagenesis [J D B]

Jet (gemology)

A bl k p qu m t r al that t kes h gh p l h Jet h been u ed f ma y c tu es f m m t l p po es It a mp ct r ty f l g te l It has a f ct dex f 1 66 (whı h a o t f r ıts r l t ly h h l t) ha d f 3–4 n M h sc le d p fic gr ty f 1 30–1 35 Jet is mp t nd d abl a d c n b arved or turned n a lathe The p cıpal o c ıs Whıtby E gl d h t occur h ed b l Alth gh popular f m Pl y d y u tıl the n e tee th cent ry th e of jet f j welry p rp es h decl ed ma kedly S Gem [R T L]

Jet flow

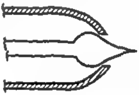
A l cal hıgh elo ty stre m a r latıvely stat n ary u r und g fl d Fl ıd may be cau ed to flow ın jet for varı ty of ea s P opul n of a body thr gh a fl ıd may b by jet pr pul ı n l y a propelle or by a mp or omp e or The ım pul e wh l u d hydro lectrıc p wer pla ts tak energy fr m a jet f w ter nd con erts ıt nt torq e appl d t a r tat g h ft In fight ng fire m oth jet f water s p od ed by nozzle to rry water t th fir w tho t separ tıng ıt nt d oplets W ter j t re ls u ed t m rth ı g ld m n g and they a u ed as m ans of dıs ıp tıng fl d e ergy

A jet may be formed by flow o t of a cl d on duıt d wn tr m f om a pr peller Flow through n rıfi e nozzle a es a jet to f rm In the case f pow d elopme t n edle n zzle s u ed to n ert the p e ure a d kı etı ergy ın the pen to k (p pe l dı f om th re rv r to the tu bı e) ınt smo th jet of v rı ble dıam ter and d ch ge but p t c lly c n ta t velo ıty (F g 1) The ha g n ı e f jet c omplı hed by movem t of th needle fo w rd b kwa d W th flow thr ugh a nozzl of fixed d ameter a ch nge n d s h ge cau s a rre p d ng h nge ı lo ty f th jet

Th f rmat o of a jet req ı es that a f rce be exerted the fl d n th d ct o f th jet An qu l and oppo te f ce ı e erted n the m ch n ca ı g th j t and th th p p l ı e fo e ın the s of an a pla e or a h p

Wh n j t of liquid ue nto a g s s ch a a wat r j t nter g ı t t rb l nc with n the lıqu d nd f ıctı n b tween s a d l qu d ca se th l q d j t e ntually t p ll ga al ng with ıt

Fıg 1 N dl



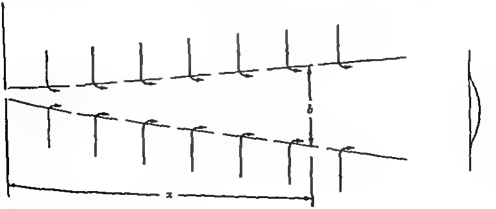


Fıg 2 Fl ıd jet h g t som fl d m d m

and to allow penetration of the gas into the stream At length the jet breaks into a spray

When a jet issues into fluid of the same den ity fluid is brought or inducted into the jet (Fig 2) The jet spreads at a linear rate with $b = x/8$ Tur bulent shear forces reduce the jet velocity within the central cone and equal turbulent hear forces act to increase velocity in the outer portions of the jet The momentum of the jet must remain substan tially constant in the axial direction because no forces act external to the jet [V L S]

Jet fuel

Requirements for jet fuels have changed as rapidly as the design of the jet engine In spite of simplic ity in principle the specifications are rigid The fuels must ignite easily under all conditions they must burn steadily without blowout or flashback and cleanly with minimal smoking or depositing they must spray well The heat content must be high to minimize the airborne weight of fuel and container the vapor pressure and freezing point must be low

These requirements are met by paraffinic kero sine or by a mixture of kerosine with ga oline fraction so chosen a to keep aromatic content below 25% A typical jet fuel is a ga oline kero sine mixture of boiling range 200–500 F and Reid vapor pressure 2–3 lb See KEROSINE [M SO]

Jet propulsion

The propulsion of a body by means of force result ing from discharge of a fluid jet This driving for e is the reaction to force exerted against the working fluid in giving it momentum in the jet stream Tur bojets ramjets and rockets are among the most widely u ed jet propulsion engine

Jet nozzles In each of these propulsion engines a jet nozzle converts potential energy of the work ing fluid into kinetic energy Hot high pre sure gas e cape through the nozzle expanding in vol ume as it drops in pressure and temperature thus gaining rearward velocity and momentum This process is governed by the laws of con ervati n of mass energy and momentum and the pressure volume temperature relationships of the ga state equation See FLUID DYNAMICS JET FLOW NOZ ZLE

For propulsion systems in which the pre ure of the working fluid is not more than approximately twice the ab olute ambient pre ure a converging nozzle is used (Fig 1a) The mass flow from th nozzle in terms of conditions at sections 1 and 2 is

$$m = A_2\rho_1\sqrt{2gJC_pT_{t1}}\sqrt{\left(\frac{p_2}{p_1}\right)^{2/\gamma} - \left(\frac{p_2}{p_1}\right)^{(\gamma+1)/\gamma}} \qquad (1)$$

and the velocity of the jet leaving the nozzle is

$$v_2 = \sqrt{2gJC_pT_1}\sqrt{1 - \left(\frac{p_2}{p_1}\right)^{(\gamma-1)/\gamma}} \qquad (\ )$$

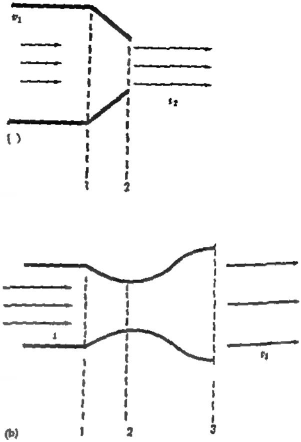


Fig 1 Propulsion nozzles (a) Low pressure converg ing nozzle (b) High pressure converging-diverging nozzle

where m = ma s flow slug/sec
A = cross sectional area ft²
ρ = density slug/ft³
J = work equivalent of heat ft lb/Btu
T = total temperature R
C_p = specific heat at constant pressure Btu/(F)(lb)
γ = ratio of specific heats
p = static pressure lb/in ²
v = velocity ft/ ec

Maximum flow occurs when

$$p_2 = p_1\left(\frac{2}{\gamma+1}\right)^{\gamma/(\gamma-1)} = p \qquad (3)$$

This is the critical pres ure at which flow velocity in the nozzle throat i equal to local ound velocity For air and m st combustion gas mixtures

$$p \simeq 0.5 p_1$$

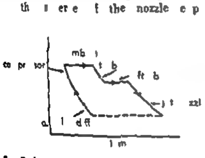
For pr pulsion systems in which the working fluid pres ure is high compared to ambient pres sure a converging diverging nozzle is used (Fig 1b) In this n zzle the working fluid continues to expand from the critical throat pre sure to am bient pre ure at secti n 3 with a further increa e in velocity beyond the sonic throat velocity

$$v_3 = \sqrt{2gJC_pT_1}\sqrt{1 - \left(\frac{p_3}{p_1}\right)^{(\gamma-1)/\gamma}} \qquad (4)$$

Turbojet. Th turb jet ı an a r b eath g propul n e g n u ed ın a rcraft Thru t r tıng r ge f m a few hund ed to 20 000 lb r more The engine ope ates be t at high ubs nıc or su person fl ght speed wher the high elocıty jet a h eves good propul ı effic n y *Se* PROPUL ıon

The tu boj t h at eng ne (ee BRAYTON CY CLE) Aır ent rs the nlet diffu e and ı om p essed ad abat cally the e d ın the rotat ng com p sso (Fg 2) Heat added by burning fu l t co ta t p es u e the ombu to Th hot ga pand n the tu bı e which drı s th c mp e s r F rthe p ı n thro gh the j t nozzle con erts th rem ng a lable e e gy f the gas st eam ınt p op l ı power (se TURBOJET) In ome turbojet m r he t ı added ı n afte burner f l f g the t rb n to ınc e e propul ıon p w r o tp t

The ı l t d ffuse dec ea e th relat e loc ty f th e t r g r ı eas g ıts pr ure ın a p o th ı er e f the nozzle e p ns n



Fg 2 T b j t p e l m d g m

Fg 3 Smplfi d h m t d g m f t b j t

(Fig 3) Fo supersonic peed a converging d v rging pa s ge ıs requı ed (*see* SUPERSONIC DIFFUSER) The diffuser th oat area may be va ıed mechan cally t match equ rements of va ying flight sp ed

The x al flow comp so shown has alternate rows of rotating and tat n ry blad s which com p e the aır furthe (Fig 4) Th r ındı ıdual ac t n ıs like th t of an aı pl ne wing ın defle tı g th a pas ıng o e ıt They a a rang d so s to c el rate nd decele ate the aır alt n tely aus ı g a p e u r t ı m ed thro gh th t pe ı g annul r pa age betwe n the rotor drum and tat r ca ng

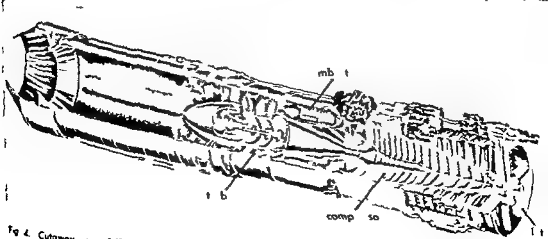
In the combust r jet fuel ke o el ke petrol um fract o ıs prayed ap ı ed and burned Aı f m th c mp e or dı cha ge fed ınto the combust on sp ce th ough l u er heet metal ombu tıo l ners They serve to m x the a r and fuel ap f r ffic nt mbustıon and to cool the lıne which p te ts the ute mbu to cas ng from the heat of the fl m

The t rb ne n zzl d ect high velo ıty gas t eam against t b bl des mo ted on wheels Th g s t rned ın th blades and by thı m men tum ha g ımp ts ergy t the wheel Th may b ev ral t rb ne tag ın eng ne co n cted by a d e haft t the compres r (Fig 5)

In th fte bu n r V sect channel are mou ted d wnst am f o n the f l sp ay b Th s ch nnels p oduc ddıe ın th gas stre m to prom te tabl b rn g nd p e nt blowo t at h gh lt t de A l ered heet m tal l ne protects the afte burne as ng from erbe t ng *Se* AFTERBUR E TURBORAMJET

F r bs fl gh t appl ns a c ergı g jet n zzle f fixed d m ns n ı u ed For sup r nı fl ght a c n g g dı erg ng j t nozzle ı sed Th d m n ı f th throat nd e ıt m be a ed t mat h th req m nt of varying flight p ed d alt tud

A c o e to the e re d ı en by an ar g m nt of hafts nd gea s tak power f m



Fg 4 Cutaway ew f J79 t b j t (G l El ct C)

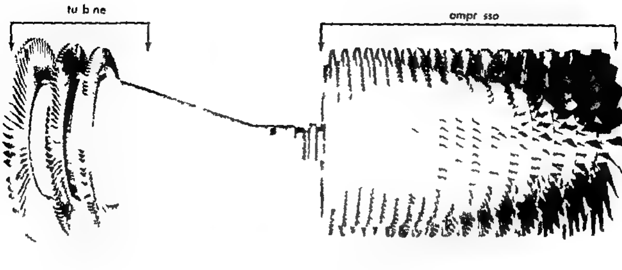


Fig 5 Compressor and turb ne r to s assembled

the compre sor turbine shaft These acces ories in clude fuel and lube oil pumps tachometer and in some installations an electric starter generator

An engine control system en es air pressure and temperature from the inlet diffuser rotor speed and throttle setting It computes from the e by mechanical or electric analog means the required fuel rates and meters fuel flow to the combustor and afterburner The system sen es gas tempera ture entering the turbine and in the afterburner from which it operates to limit fuel rates so as to prevent overheating or over peeding Engine char acteristics repre entative of a modern turbojet are given in Table 1

Table 1 Characteristics of med um sized turbojet

Char cte t cs	W th aft rl	W th ut ft bu n
W ght ll	3 600	2 900
Lengtl n	00	110
D m t r	38	37
Comp ess r st ges	17	17
T b e stag	3	3
Tak ff th t ll	15 500	11 000
Tak -off SFC	0	0 8
Best c u th u t ll	600	500
Best SFC (M h 0 9 at 3 000 ft lt t de)	1 0	0 9
M l t ry tl t ll	6 000	
M l t ry SFC (M ch ll t 5 000 ft lt t l)	3	

Spec f c fu l co mpt po l f fu l per po d f thr st p h u

Ramjet The ramjet i the simple t air breath ing propul ion ystem and is u ed principally in guided mi ile (Fig 6) It travels at high velo ity compre ing air in it inlet diff i er burning fuel in the air and di charging it through a jet nozzle There are no rotating compre or and turl ine in the ramjet The ram air pre ure rati achieved l y its forward velocity are high enough for efficient operation on the Brayton cycle Howe er the ram jet must be accelerated up to operating peeds b other mean In most missile application thi i accomplished by a rocket powered boo ter tage

Characteristics repre entative of a modern ram jet are

Weight lb	1000
Length in	150
Diameter in	36
Thru t lb	2000
Specific fuel con umption (Mach 4 at 75 000 ft altitude)	2 0

The ramjet is usually designed to crui e within a fairly narrow speed range The coml u tor i imi lar to a turbojet afterl urner with fuel injector V channel flame holders and a louvered lin r f r heat insulation Control and acce orie h u ed in the l ullet nose of the inlet are powered l y a very mall high speed turl ine dri en l y ram air bled from the inlet S e RAMJET s e also PULSE JET

Liquid propellant rocket engine The liquid propellant rocket engin is a propul i n s tem u ed to power mi sile and pace vehicle It i u ed primarily t accelerate a load to high vel city and to do thi d li er a large thru t for a rela tively sh rt time interval

Liquid fuel (u ually a hydr carl n re mbling kero ine) and oxidizer (u ually liquid oxygen) are p imped from tank to a fu l inj ctor which pray them int a c ml u ti n chaml er in which they l urn Th h t ml u ti n g e ape thr ugh a jet nozzle lea ing at v ry higl elocity (Fig 7) The reacti n f r e l el ped on n zzle wall a d inje tor head are tran mitted to tl e l ly f the vehi le Ro ket ehicle re m time st red l y m unting tl e entire engin n giml al

Fuel and oxidiz r pump ha e higl p e l cen trif gal impeller dri en tl e gl pe l re l cti n

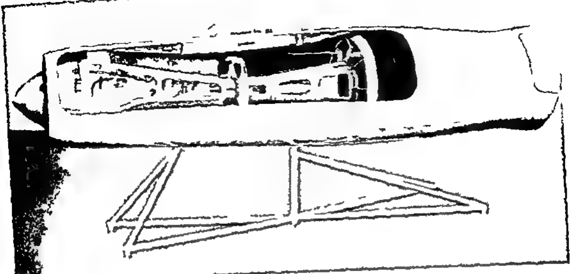


Fig. 6 C t w y mod l f am t (Mo qu dt A ll Co)

us by a sm ll gle stage g s t rb ne H gh n g s t d v the t b e u lly t ob ed by b rn ng f l and ox dı er bl d f om th mp d sch rg to small mbu ti chamber ed g th t rb e St rt g ac mpl h d by orn ng the p pell t f m gas pr s ized ks. I som rocket eng nes th t b e wo ki g d d comp ed hydrogen p ro id See PRO- ELLA T ROCKET ENGI E

The effect en f rocket p pellant e mb t ı nd c ted by t theor t l sp ific im

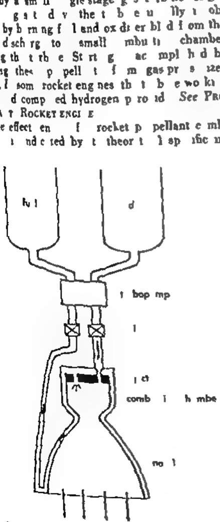


Fig. 7 Liquid-propell t ock t g (G l Electric Co)

T ble 2. Theoretical v l es f everal liq l-oxidize combi t ons (1000 p l comb st on hambe press e)

Comb ti ns	I_{sp}, ec
Liq d xyg JP1	86
Liq d yg l q d hydrog	388
Hydrogen pero de-JP1	66
N_2O UDMH†	274

JP1 k ros l k hydroca bon
† N trogent tro de-unsymm t cal d m thylhydrazin

pul e F ls a d o d ze s of l w molecul w ight re p efe red bec u e fo a gi n energy rele n nd ma fl w the l ghtw ight molec le a hie e gr at t el ty nd n eque tly h ghest specific mpul e I_{sp}.

Typic l cha acteri tics of a large l qu d propel l nt rock t eng ne ar a follows

P opellant	Liquid oxyg n–JP1
Ch mb r pres ure p	900
Thru t lb	00 000
He ght in	170
N zzle ex t d amet r in	60
O er all I_{sp} ec (t 100 000 ft alt tud)	284
B n t me e	200
Weight (not ı l di g fu l o fuel tank) lb	2000

Solid propellant rocket engine The sol d pro- p ll t o k t e gı p op l ı n sy t m u ed t m ıf s nd p h l It c n deli la ge th t a d ıs ın ta tly r dy fo pe t on

This g c ns ts f a ca ıng filled with a mı tu e f prop lla t h m l ın ld f rm Th b rn g ner tı g h t h gh p re g es wh ch es- pe th gh ozzl as h gh el city jet c t ng f rward th t r t To teer th eh l me nozzl r c n tru ted so th t th y can b

A large engine such as the first stage of a 1500 mile ballistic missile might have these general characteristics

Propellant	Potassium perchlorate polyurethene and additives
Length in	220
Diameter in	50
Gross weight lb	20 000
Average thrust lb	80 000
Burn time sec	60
Over all I_{sp} sec	230

Propellant combinations are selected to contain as much fuel and oxidizer and as little inert substance as possible As with liquid propellants combinations with low molecular weights are preferred because they result in greater specific impulse for a given energy release The propellant mixture must burn at a relatively slow uniform rate certain inhibitors are added to control this

There are now in use a variety of propellants of two general classes Double base types contain nitrocellulose and nitroglycerin plus additives for stability and to control combustion rates Composite types contain ammonium or potassium perchlorate granules imbedded in a rubberlike hydrocarbon compound *See also* ELECTROMAGNETIC PROPULSION [D C]

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Jet stream

A relatively narrow fast moving wind current flanked by more slowly moving currents Jet streams are observed principally in the zone of prevailing westerlies above the lower troposphere and in most cases reach maximum intensity with regard both to speed and to concentration near the tropopause At a given time the position and intensity of the jet stream may significantly influence aircraft operations because of the great speed of the wind at the jet core and the rapid spatial variation of wind speed in its vicinity Lying in the zone of maximum temperature contrast between cold air masses to the north and warm air masses to the south the position of the jet stream on a given day usually coincides in part with the regions of greatest storminess in the lower troposphere though portions of the jet stream occur over regions which are entirely devoid of cloud

Characteristics The specific characteristics of the jet stream depend upon whether the reference is to a single instantaneous flow pattern or to an averaged circulation pattern such as one averaged with respect to time or averaged with respect both to time and to longitude

If the winter circulation pattern on the Northern Hemisphere is averaged with respect to both time and longitude a westerly jet stream is found at an elevation of about 13 kilometers (km) near latitude 25 The speed of the averaged wind at the jet core is about 148 km/hr (80 knots) In summer this jet is displaced poleward to a position near latitude 42 It is found at an elevation of about 12 km with a maximum speed of about 56 km/hr (30 knots) In both seasons a speed equal to one-half the peak value is found approximately 15 of latitude south 20 of latitude north and 5-10 km above and below the location of the jet core itself

If the winter circulation is averaged only with respect to time it is found that both the intensity and the latitude of the westerly jet stream vary from one sector of the Northern Hemisphere to another The most intense portion with a maximum speed of about 185 km/hr (100 knots) lies over the extreme western portion of the North Pacific Ocean at about latitude 22 Lesser maxima of about 157 km/hr (85 knots) are found at latitude 35 over the east coast of North America and at latitude 21 over the eastern Sahara and over the Arabian Sea In summer maxima are found at latitude 46 over the Great Lakes region at latitude 40 over the western Mediterranean Sea and at latitude 35 over the central North Pacific Ocean Peak speeds in these regions range between 74 and 83 km/hr (40 and 45 knots) The degree of concentration of these jet streams as measured by the distance from the core to the position at which the speed is one half the core speed is only slightly greater than the degree of concentration of the jet stream averaged with respect to time and longitude At both seasons and at all longitudes the elevation of these jet streams varies between 11 and 14 km

Variations On individual days there is a considerable latitudinal variability of the jet stream particularly in the western North American and western European sectors It is principally for this reason that the time averaged jet stream is not well defined in these regions There is also a great day to day variability in the intensity of the jet stream throughout the hemisphere On a given winter day speeds in the jet core may exceed 370 km/hr (200 knots) for a distance of several hundred miles along the direction of the wind Lateral wind shears in the direction normal to the jet stream frequently attain values as high as 100 knots per 300 nautical miles (185 km/hr/556 km) to the right of the direction of the jet stream current and as high as 100 knots per 100 nautical miles (185 km/hr/185 km) to the left Vertical shears below and above the jet core are often as large as 20 knots/1000 ft (37 km/305 m)

Daily jet streams are predominantly westerly but northerly southerly and even easterly jet streams may occur in middle or high latitudes when ridges and troughs in the normal westerly current are particularly pronounced or when unusually intense cyclones and anticyclones occur at upper levels

Insufficiency of data on the Southern Hemisphere precludes a detailed description of the jet stream but it appears that the major characteristics are embl quit clo ly tho e f the jet stream of the Northern Hemisphere The day-to-day variability of the jet stream however appears to be less on the Southern Hemisphere

It appears that a jet stream occurs at high latitudes in both hemispheres in the winter stratosphere at elevations about 20 km The data available however are insufficient to permit the precise location and detailed description of this phenomenon See AIR MASS; AIR WAVES, UPPER; SYNOPTIC; ATMOSPHERE; GEOSTROPHIC WIND; STORM; VORTEX. [F S]

Jet velocity

The velocity of the engine exhaust gases relative to the exhaust nozzle In an air-breathing cycle it is assumed that the fuel-to-air mass rate is small and that the inlet air mass rate equals the mass rate of fuel burned can be neglected and that the exhaust gases are expanded to ambient pressure in the nozzle Under these conditions the thrust of an engine is directly proportional to the air flow rate and to the difference between the jet and flight velocities thrust is greatest at zero flight speed and becomes zero when the flight speed is the same as the jet velocity

Both engine power and efficiency ... proportional to the product of the ... times flight velocity Therefore both power and efficiency ... zero flight speed and also zero when flight speed equals jet velocity Between these limits the engine ... of jet velocity to flight speed ... maximum power and efficiency and jet velocity becomes ... of engine exhaust nozzles ... turbojet jet velocity can be controlled ... by varying the ... of the ... by ... enough ... ments The ... shell is a ... form ... able ... r multiple ... tent ... nozzle

... turbojet with ... after burner ... nozzle ... efficiency ... nozzle may be ... during ... of ... flight ... used ... both ... ternal ... jet efficiency

In the ... breathing rocket ... the above ... depend ... of flight speed ... directly ... jet velocity plus ... See PROPULSION.

Jetty

An artificial barrier at river mouths and harbor entrances to deflect and regulate the flow and tidal current particularly in areas where littoral drift causes formation of bars across channel entrances Jetties are built singly or in pairs curved or straight to prevent littoral drift across a channel and to increase the velocity of tidal flow which keeps the channel deep Jetties are constructed to suit natural conditions and often resemble breakwaters Although solid sheet pile walls of timber, concrete and steel have been used ... extensively A fine example is the 4½-mile jetty at the mouth of the Columbia River Oregon See COASTAL ENGINEERING; RIVER ENGINEERING. [E J Q]

Jig, fixture, and die design

The planning of tools for use in making production parts Jigs position parts for machining operations such as drilling milling reaming and boring and they physically guide the cutting tool Fixtures position parts for machining welding or assembly operations but permit cutting tools to find their own path Dies are tools which when mounted in presses produce parts by punching and forming

Jig and fixture construction For ... steel ... after welding and with hardened ... has generally ... eded ... jig and fixture construction Aluminum and magnesium are used ... app ... because they are lighter to handle and less costly to fabricate and machine When ... such as those ... aircraft industries the epoxy resin ... with fiberglass ... suitable material can be used ... with hard ... and bushing ... low melting point alloy ... difficult ... plated

Locating methods The accuracy obtained by jigs and fixtures depends upon the accuracy with which parts ... maintained ... the first and subsequent jigs or fixtures The dimension ... of the part itself ... the ... fixture ... operations ... in the part ... form ... milled ... which can be used in subsequent operations ... should be used for as many operations as possible

Clamping may deform the part if the locating ... are not selected judiciously Locating points should be placed ... part ... ing the need for adequate support and ... Three ... small pads determine ... plane and ... stop ... determine locations within the plane (Fig 1)

The use of two or more straight pins ... bles ... locating from holes because slight dimensional ... between holes will make it difficult

A large engine such as the first stage of a 1500 mile ballistic missile might have these general characteristics

Propellant	I otassium perchlorate polyurethene and additives
Length in	220
Diameter in	50
Gross weight lb	20 000
Average thrust lb	80 000
Burn time sec	60
Over all I_{sp} sec	230

Propellant combinations are elected to contain as much fuel and oxidizer and as little inert sub stance as po sible As with liquid propellants com binations with low molecular weights are preferred becau e they result in greater specific impul e for a given energy release The propellant mixture must burn at a relatively slow uniform rate cer tain inhibitors are added to control thi

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Characteristics The specif c l aracteri tic of the jet tream depend up n whether the referen e i to a single in tantaneous flow pattern or to an averaged circulation pattern such a one averaged with re pect to time r averaged with resp ct l oth to time and to longitude

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If the winter circulation is averaged only wit respe t to time it is found that both the inten i and the latitude of the we terly jet tream va from one sector of the Northern Hemi phere t another The most intense portion with a maximu speed of about 185 km/hr (100 knots) lies ove the extreme we tern portion of the North Pacifi Ocean at about latitude 22 Le er maxima o about 157 km/hr (85 knots) are found at lat tude 35 over the east coast of North America an at latitude 21 over the eastern Sahara and ove the Arabian Sea In summer maxima are found a latitude 46 over the Great I akes region at latitud 40 over the western Mediterranean Sea and at lati tude 35 over the central North Pacific O ean Peak speeds in the e regions range between 7 and 83 km/hr (40 and 45 knot) The degree o concentration of the e jet treams a mea ured b the distance from the core to the po ition at which the sp ed is one half the core peed i only lightl greater than the degree of concentration of the jet stream averaged with re pect to time and l ngitude At both sea ons and at all longitudes the ele ati n of the e jet treams varie between 11 and 13 km

Variations On individual days there i a c d eral le latitudinal varial ility of the jet stream par ticularly in the western N rth American and we t ern European ectors It is principally f r thi rea s n that the tim averaged jet tream is n t well def ne l in the e region There i al o a great day to day arial ility in the inten ity of the jet tream through it the hemi phere On a given winter day sp eed in th jet c e may exceed 3 0 km/hr (200 kn t) f r a di tan e of everal hundred miles al ng the lire tion of the wind Lateral wind shear in the dire ti n normal to the jet stream frequ ntly attain value a high a 100 knots per 300 nautical mile (18 km hr 55(km) to the rigl t of the di re ti n f the jet tream rrent and a high as 100 knot per 100 nau ti al miles (185 km/hr/185 km) to the left Verti al shears l elow and abo e tl e jet or are ften a large a 20 knot /1000 ft (37 km 30 m)

Daily jet tr am a pre l minantly we terly l t n rtherly utherly and e n ea terly jet tream may o r in mi l l or high latitudes when ri lges an l t ugh in th n rmal we terly current are par tic ilarly r noi n e l r wh n i nu i all inten e cy cl nes and anticycl n occ r at up r le l

In sufficiency of data on the Southern Hemisphere ... detailed description of the jet stream ... but it appears that the major characteristics ... ble quite closely those of the jet streams on the Northern Hemisphere. The day-to-day variability of the jet stream ... appear to be less on the Southern Hemisphere.

It appears that an ... jet stream ... at high latitude on both hemispheres ... the winter stratosphere at elevations above 20 km. The data available ... sufficient to permit the precise location or detailed description of this phenomenon. See AIR MASS; AIR WAVES, UPPER SYNOPTIC; ATMOSPHERE; GEOSTROPHIC WIND; STORM; VORTEX. [F.S.]

Jet velocity

The velocity of the ... gases ... exhaust ... gases ... relative to the exhaust nozzle. In ... the ... cycle it is assumed that the exhaust gas mass ... equal ... the mass ... of fuel being ... neglected and that the exhaust gases are expanded ... to the nozzle. Under these ... the thrust of an engine ... directly proportional to the ... flow rate and to the difference between the jet ... velocities ... greatest at zero flight speed and becomes ... when the flight speed is the same ... the jet velocity.

Both engine power ... efficiency ... product of thrust times flight velocity. ... both power and efficiency ... flight speed ... and also ... when flight speed equals jet velocity. Between these limits ... of jet velocity to flight speed ... maximum power and efficiency ... jet velocity becomes ... in the design of engine exhaust nozzles. ... turbojet ... jet velocity can be controlled ... by varying the opening ... of the exhaust nozzle by any of several arrangements. The clamshell ... nearly form ... able nozzle ... multiple ... designs ... Internal plug ... used to vary ... nozzle.

... turbojet with afterburner ... ample convergent variable-area ... that ... nozzle ... turbojet ... exhaust ... turbojet with ... afterburner ... variable-area nozzle ... required ... flight ... performance ... at ... flight ... both ... nozzles ... both ... jet efficiency ... rocket ... the above ... not apply ... flight speed ... thrust ... directly proportional ... nozzle ... jet velocity ...

Jetty

An artificial barrier ... river mouths and harbor ... to ... deflect and regulate river flow and tidal currents ... particularly in areas where littoral drift causes formation of bars across channel entrances. Jetties are built singly or in pairs, curved or straight, to prevent littoral drift across ... channel and to increase velocity of tidal flow, which keeps the channel open. Jetties are constructed to suit natural conditions and often resemble breakwaters, although ... sheet pile wall of timber ... concrete ... and steel have been used extensively. A fine example is the 4½-mile jetty at the mouth of the Columbia River, Oregon. See COASTAL ENGINEERING; RIVER ENGINEERING. [E.J.Q.]

Jig, fixture, and die design

The planning of tools for use in making production parts. Jigs position parts for machining operations such as drilling, milling, reaming, and boring, and they physically guide the cutting tools. Fixtures position parts for machining, welding, or assembly operations but permit cutting tools to find their own path. Dies are tools which, when mounted in a press, produce parts by punching and forming.

Jig and fixture construction. Fabricated steel ... welded ... with hardened steel inserts at the wear points ... generally superseded ... jig and fixture construction. Aluminum and magnesium are used for many applications because they are lighter to handle and less costly to fabricate and machine. When large parts ... such as those in ... aircraft ... epoxy resins reinforced with fiberglass ... suitable material ... can be used in conjunction with hardened steel ... bushings ... and other low melting point alloys ... required where ... must be duplicated.

Locating methods. The accuracies obtained by jigs and fixtures depend upon the accuracy with which parts can be consistently positioned in the fixture and subsequent jig ... fixture. The ... of the part ... is ... fact ... On ... locating points ... the ... jig or fixture ... operations ... locating points on the part ... milled ... surface or hole ... which ... same locating points should be used for as many operations as possible.

... the part ... locating points ... geometrically. Locating points should be spaced as far apart as the part design permits ... need for adequate support and ... plane and stop ... (Fig. 1).

The ... of two ... straight ... locating from holes ... between holes ...

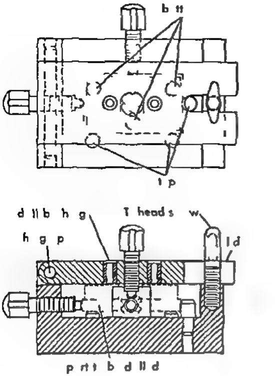

Fig 1 Buttons and stops locate part in drill jig

ficult to load or unload the part The most common method is to use one round pin and one diamond or elliptical pin (Fig 2)

Self centering devices must be used when it is necessary to locate centrally from two surfaces that can vary When locating round parts it is preferable to work from hardened V shaped locators The angle of the V should be 90 Sight holes should be provided to permit the operator to observe visually whether or not the part is down on stops and buttons Where practical multiple station jigs and fixtures should be made in such a way that parts can be loaded while others are being machined The cost of loading or unloading parts is often greater than the machining cost

Clamping The clamping arrangement should be simple Clamping pressure is applied over or between the pads or buttons and standard vises are adapted as machining fixtures where practical Machining is done toward the fixed jaw Standard air cylinders are used If more than three supports in one plane are necessary all in excess of three should be adjustable Where a wrench must be used all nuts should be standardized Large hand knobs ensure ease of operation and cam type clamps are usually faster and more positive than other method

Tool guides In jigs tool guides consist of bushings that guide drills reamers and boring bars American Standard Association size should be used when possible Bushings normally extend as close to the part as practical to assure accuracy of hole location and to eliminate chip tangle within the jig

The use of slip-removable bushings in hardened liner permits secondary operation such as tapping reaming and counterboring Where accuracy demands reamers may also be guided in lip bushings either by pilots or by their cutting edges

Tool guides in fixtures are limited to set pieces for establishing a relationship between the cutting tools and the fixture These are permanently located on the fixture and clearance is allowed between the set pieces and the cutting tools A feeler gage the thickness of the clearance is then used to locate and set the cutting tools

Chip control During drilling chips are either brought out through the bushing by allowing zero clearance between the bushing and the part or permitted to stay in the jig by allowing sufficient clearance for that purpose The former method is the more desirable but if tolerances are not critical and the chips are discontinuous wear on the bushings can be reduced by the latter method To compromise between zero and ample clearance creates the disadvantages of both with none of their advantages

Jigs and fixtures are designed with sufficient openings for chips to be removed by gravity coolant flow brush or air blast Dust collectors are used to collect dry grinding chips or chips of nonmetallic or toxic materials

Safety Practice dictates the use of ½–13-in or larger tapped holes for eyebolts in all jigs or fixtures weighing 50 lb or more and the removal of all sharp corners that could injure operators

Stamping dies Dies produce parts either by stressing the part material in shear until fracture occurs or by stressing the part material beyond the yield point where it takes a permanent set but not beyond the rupture point where it breaks Dies using the former method include blanking piercing cut off and lancing dies and those employing the latter method include drawing bending embossing

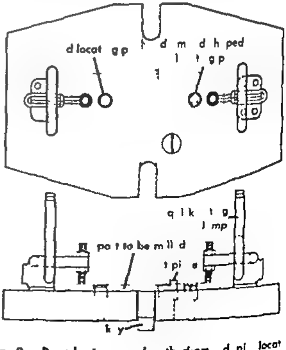

Fig 2 Round pin paired with diamond pin locates part and allows part to be loaded easily in milling fixture

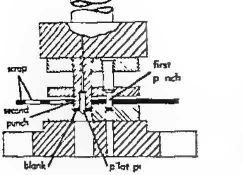

Fig. 3 P g ess ve d p rf rm ev l p t equen lly mat rial adv from first to ec d punch betwee strokes.

and f rming dies Any p actic l comb nat n of the ...ow th per ti be in l ded in o d. and can be perf rmed ith m llaneou ly o m it ps u.m a pr gres ive-type d e (F g 3)

Di nstructi Con e t n l t mp e d es are composed f th f ll wi g main parts the d set, co tin f t p and bott m hoes gu d pi ad b h gs the pun h, whi h s th male cutt g r f rming member th d whi h s the femal cutting o f rm g member trippers that emov th p rt from th p h d e gages t loc te the p rt part m terial a d bl nk h lders that re- mov wri kles nd e a even fl w of material m d. wing (F g. 4)

Di s l cti The d type elected fo a j b determined by p rt des gn d eco m co d ra tions, h as th umber of p eces t be prod ed. cost f alternat methods of p oduct on, and ma n tena f th tool tself

Very l w ctivit es l be l part tole nces of te j tity pec l types f d es s h teel rul d plow teel d es f r cutti g pe ati n a d pla ti rubb dies f r f rm g per ti Most urat m l ing mode t t h gh ctiv t es d es empl y g h dened tool teel

La g ctivit es m t mes j t fy th high cost f d s m d f m tu g ten a b d Well-de- gned d ll b ilt t gsten carb de dies c n turn out a la g l m f e t mely cu t part at h gh peeds w th littl h pening ar

Mat rials f t mping A m teri l softer than th pun h and d d which will n t h tter h impact m y be cut, p e ed bl ked in d. f d g be di g a d f rm g per t o ductil t m the p m equ t Spri gb d d orm tio s. lud g ha ges in m teri l th k ness occurs g d ri g the f rm g pe ti n, a takes int en d t n. M t rial t ed ther d idually h ed p eces trip co l f rm. S p or coiled mat ri l m kes pos bl the se f ...ous feed g mech m w th es lt t l bor economies not u ally p s t al w th h ared ma terial les a f lly t m ted set p prov ded.

pi g tol Obt bl es a d m r ge d pending on th p rt mate al,

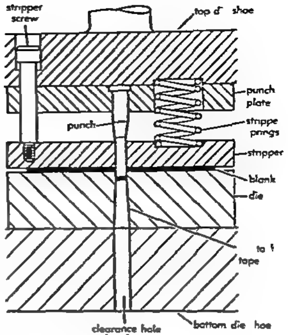

Fig 4 Main p rts f nve t f stamp g dies. ( ) F pie ing (b) F bla ki g and drawing

th ck es f tock bei g pun hed, izes and part co figur t n, and th xim ty of bend or h les A cu c es of ± 0.0005 in are obtainabl n thin m t ri l ng compound type dies h wever un- d n rm l pe ti g co diti n practical t ler nces l ght m teri l can be expected t ary f m ± 0.002 n. t ± 0.010 in d on h vy m te ri l f m 0.010 in. t 0.035 n T a d d t rti n, h les ar pl ed d t c no les than th mate- ri l th ckness from th ed f an ther h l and no les th three times th mat ri l thicknes fr m a be d r d us H l locat n establ h d

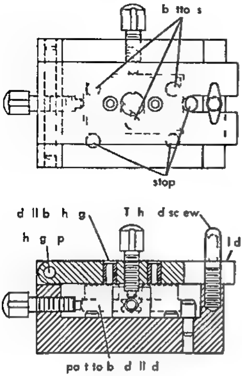

Fig 1 Buttons and stops locate part d ill j g

ficult to load or unload the part The most common method is to use one round pin and one diamond or elliptical pin (Fig 2)

Self centering devices must be used when it is necessary to locate centrally from two surfaces that can vary When locating round parts it is prefera ble to work from hardened V haped locators The angle of the V should be 90 Sight holes should be provided to permit the operator to ob erve vis ually whether or not the part is down on stops and buttons Where practical multiple station jigs and fixtures should be made in such a way that parts can be loaded while others are being ma chined The co t of loading or unloading parts is often greater than the machining co t

Clamping The clamping arrangement should be simple Clamping pressure is applied over or be tween the pads or button and standard vi e are adapted as machining fixtures where practical Ma chining is done toward the fixed jaw Standard air cylinder are u ed If more than three upp rts in one plane are nece ary all in exce s of three should be adju table Where a wrench must be u ed all nuts hould be standardized Large hand kn b ensure ea e of operation and cam type clamp are u ually fa ter and more po itive than other meth ods

Tool guides In jig tool guides con i t of bu h ings that guide drill reamers and boring bar American Standard A ciati n izes h uld be u ed when po il le Bu hing normally extend as clo e to the part as practical to a ure accuracy of hole location and to eliminate chip tangle within the jig

The u e of slip-remo al le bu hing in harden d liner permit ec ndary operation such as tap ... reaming and counterboring Where accuracy demands reamers may al o be guided in lip bu h ings either by pilots or by their cutting edges

Tool guides in fixtures are limited to et pieces for establishing a relation hip between the cutting tools and the fixture The e are permanently located on the fixture and clearance is allowed between the set pieces and the cutting tools A feeler gage the thickness of the clearance i then u ed to locate and et the cutting tools

Chip control During drilling chips are either brought out through the bushing by allowing zero clearance between the bu hing and the part or per mitted to tay in the jig by allowing ufficient clearance for that purpo e The former method is the more desirable but if tolerances are not criti cal and the chips are di continuou wear on the bushings can be reduced by the latter method To compromise between zero and ample clearance creates the disadvantage of both with none of their advantages

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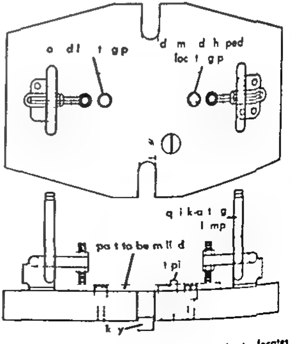
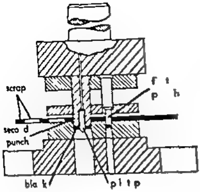


Fig 2 Ro d pin pai ed with d mo d pi locates pa t a d allow part to b loaded readily i m ll g f t



Fg 3 P og ess d p rf m l p t seq lly m t l d t f m Frst t d p ch betw k

and forming d Any pr ti l comb natio f tl above r oth perat an be ncl d d e de and n be p formed e the m ltanenu l r m t ps u g p ogre e-t pe d e (F g 3)

D nst u t Co e t al tamp ng d e ar mposed f the f ll w g ma p rt th d e set, c ting f t p a d bott m hoe gu de p n a d b h p th p ch which i th male utt ng r f rmi g m mber the d wh ch the f m le uttmg r f rm g memb t ipp th t rem e th p rt f om the p ch d e g ges to locat th part o p rt mat r al and bl nk h lde th t re m ri kle d ca e e flow of mat ri l m d awing (F g 4)

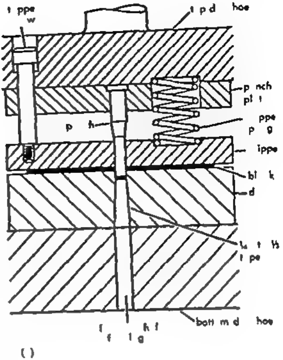
Di l ct Th d type l ted f a j b i d t rmined b p t d gn d e om d ra ti ns, h th n mber f p eces t b p odu ed t f alt rnat m thod f p od ctio a d m n ten l th tool t elf

V ry l w t vit l be l part t le n f ten j t fy p l types f d es h teel le d es o pl w st el d es f r cutt g per t on a d pl t bb d es f f m g pe t ns Mo t ppl to t ol i g m d at t h gh a t t qu d e empl y g h de ed tool teel

La ge ct it ca met mes ju tify the h gh cost f d m d f m t g t carb d Well de gned a d ll b lt t gste c b d d an t m t l g l me f t m ly c t part t h gh sp ed w th l ttle ha pens pat

Mat rial f t mp g A y m t i l fter th the p h a d d d wh ch w ll not hatt th mp t m y h t p d bl nked n d l d a g b d g and f rmi g op ti n d ctil ty i th p m q t Sp gb k a d d l rm t i l d ng nge n mater al thi k oe ri g d g th f rm g p ll a e tak t t de ti Mat l u d th r i md d lly h ed p n tr p r l f rm t p c led m t r l m ke p bl th f a io feed ng mech m w th lt t lab r ec m n t u lly p et c l w th h d m ten l les f lly t m ted t p s p d d

St mp g t l c Obt ble u b d r ng d pe d g th p rt m te l



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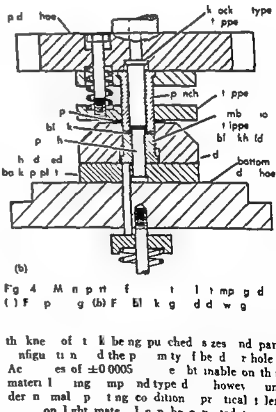


(b)

Fg 4 M n p rt f t l t mp g d ( ) F p g (b) F Bl k g d d w g

th kne of t k be ng pu ched s zes nd part nfigu ti n d the p m ty f be d r hole Ac es of ±0 0005 e bt inable on th n materi l ing mp nd type d howev un der n mal p t ng co dition pr tical t ler on l ght mate l c n be e p ted to ary f m ±0 002 to ±0 010 d n h y m te l f om 0 010 in to 0 035 i T d d st rt n hole pla ed a d t e le th n th m t l thick f m th edg of th h le d le th n th t mes the m t ial thi kn s f m d du H l l t e t bl hed p e-

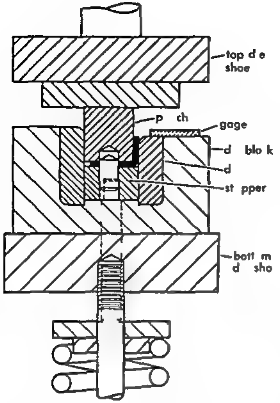


Fig 5 Bending die showing adequate clearance between hole and bend

vious to bending operations are subject to material thickness tolerances and the stretch of the material which occurs during the bending operations (Fig 5)

General design A tool lineup is made to determine the sequence of operations and the type and number of dies required to complete the part or blank A blank layout is made to obtain optimum material usage and to reduce scrap (Fig 6) and the material is checked to make sure the burr is on an acceptable side of the blank Material is normally fed into the die from right to left or front to back When tolerances permit the finished edge of the stock can be used as a side of the blank

Tonnage to shear or form is computed and the die is designed for a press that will handle this capacity It is generally possible to improve die life by using a press rated for twice the required capacity Work can be performed on presses of less than the computed capacity by staggering the lengths of punches or by adding shear to the punch or die Safety requires that tapped holes be pro-

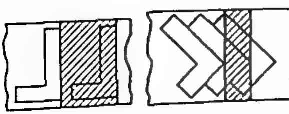


Fig 6 Bl k layo t compa amo t of m te ial ... (sh ded p rt o s) by two

vided for eyebolts in dies 50 lb or more in weight and that safety bolts be provided to hold the die together when not in use Guards and undercuts are applied to dies to protect the hands of the operator Standard punches and die inserts for round, oblong square or rectangular holes can be purchased in small increments of size and are readily available for replacement when breakage occurs. *See* MACHINING OPERATIONS METAL FORMING SHEET METAL FORMING [R.L.C.]

Bibliography F Wilson (ed) *Tool Engineers Handbook* 1949

Johne s disease

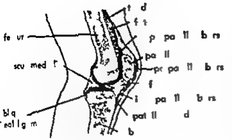
A specific enteritis or inflammation of the gastrointestinal tract of cattle sheep and deer caused by the bacterium *Mycobacterium paratuberculosis* The disease is spread by animals having eaten the droppings of sick animals and is diagnosed by the clinical symptoms the presence of *M paratuberculosis* in the droppings and by a positive skin reaction to johnin a preparation similar to tuberculin *M paratuberculosis* is a short thick acid fast rod which can be artificially cultivated only on media containing a substance or substances as yet unidentified present in extracts of acid fast bacilli and of certain plants The disease has an incubation period of a year or more Sick animals have intermittent diarrhea without fever and gradually become emaciated The mucosa of the small intestine shows gross thickening and the mesenteric lymph nodes enlarge without ulceration Caseation (death of tissue with change to a cheeselike consistency) and calcification do not occur The drugs streptomycin viomycin 4 4 diaminodiphenylsulfone and isonicotinic acid hydrazide although used successfully in the treatment of tuberculosis have been used without success in the treatment of Johne s disease Animals that have Johne s disease must be destroyed because they rarely recover and present a focus of infection for other animals in the herd *See* TUBERCULOSIS [C.H.M.]

Joint (anatomical)

The region or point of contact between bony surfaces also known as an articulation There are three general types of articulation the synarthrosis or immovable the amphiarthrosis or slightly movable and the diarthrosis or freely movable

Synarthroses include those immovable joints where the bony surfaces are fixed but usually separated slightly by a small amount of fibrous tissue or cartilage These include the sutures of the skull and the type known as synchondrosis where a piece of cartilage acts as a temporary form of articulation The latter condition is seen in children before the cartilage is converted into the bone of adult life Other special forms of synarthrosis occur such as gomphosis the insertion of the teeth into the bony sockets or alveoli of the jaw

In the slightly movable or amphiarthrotic joints the opposing bony surfaces are separated by a flattened cartilaginous disk often of rather complex



lat l w f k j t (F m N L H d A
O l d Bl k st N w G ld M d I Dct ry
2d ed Bl k st 1956)

t b l art l tt s d the ligame t att h me t b t e the t b and th fibula at the ankl

D arthro es r ma ked by a syn l memb h h f rm cl ed bout the opposing bo es I ddit the d f the b es are ed with pe l d f m f rt l i g cartilage d pted f m me t. The fl d of th vn ial j int a t s a lub c t Th e may lso be a ar ticular di k b t e the two pr c pal s rfa s to ct as a f th a d to m me t

Th d arth e en med c rd g t tl type of m t n n l ed n them The hi g j t or gi glym s p rmits m t ly n one pl ne th fi g k e d lb w j ts e e mple The p t j int, r t och d e t cted t a r tat on f bo b t a the Th t t of the atlas bo t the x s, s cond rv l v teb a typ e l. Th ball d ock t j t, or e a th os s hara t t of the h p d h uld art l t in h h wid ra f m t ll pl es is p bl Cl d j ts o rth od p rm t nly est ct d m ti n b twee c a d a ex f Th type u ome f th wr t nd kl bo rt l t n S ANKLE WRIST

Co dyl d rt lat o f rm d by an d s f e wh h fits t ll pt) ty that all m ements pt t t p rm tted Th wr t j int i an mpl f thi typ

Th t n of m ti p rm tted by o a j ts m b t t d t n k d f m m t m y be mb n t dep d ng th l ti a d d l pm nt l f tu I dd t rt in d d l b w a wid r f m t n th th p rt la l f j r m lf rmed di d f m t j int f th m bl typ th a d fi ni rra g m t f t t c l l g m t b h f h t gth nd pp t S MUSCULAR SYSTEM SKELETAL SYSTEM

[E G S T]

Joint (anatomical) disorders

Local o g lized d t wh h ff t th j nts nd el ted t u Ab t e p 25 h m f rm f j t d t b c Th most m m n ar form f rth t s, nfl mm t f j t stru tures. Th e may f ll w sp cific f t njury g lized d a t t d g ne t e h nges h h l g ly p llel the ag g p in th body

The arthritis of rheumatic fever is fairly charac teristic in that joint in ol ement is usually migra tory and coincides with the clinical state Although the exact cause is unknown a form of hypersensi ti ity to a prior treptococcal infection is appar ently contributory

Rheum to d arthritis one of the mo t common di eases which in l es j ints is also of unkn wn etiol gy but agai hypersen itivity is related as well as oth r factors It occurs mo t often in yo ng or middle aged adult and ha a m rked tendency t de go p t rem n Multiple joints a e i ol ed pec ally th e of the sm ll bone in the hands feet, wri ts r jaw In many affected p there i a clo e correlati n b tween symp-toms and m t nal t te

Oth r so-called coll gen di ea es such a lupus erythe m to a d periarteriti od a freque tly are accompanied by a th itis much l ke the rhe m to d var ty

Degenerati j int di e e is most mmon in old r people The maj r form steoarthr ti is m ked by d te ration f the articular rfaces of the we ght beari g joints of the knee hip and spin The end f the fi ge s are often invol ed

Arthrit m y be produc d by t auma u ta ned f m a ingle ti s -damag g i jury from re t d phy l t sult to a p rti lar j int

I fecti arthr t s may be ed by g norrhea r in on t y pne mococ t eptococ i a d othe p th g ic o g ni ms Special form more chr c in ture are ee n t berculos a d syph lis

Gout s an e mpl f arthrit s ca sed by meta b l c d ord I this i ta ce there is n abn r m l ty f p ine b eakd wn that produc accumu l t of r c a d a d ur tes in j int ti es The phy cal fi di and cl ical c ur are u lly d t ti

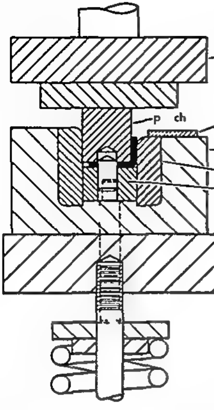
J nt d ord s m y be f nd i certai rv us sy t m d ase pa ticul rly th se wh ch affect the l c d Sy i gomyelia syph lis (tabes d r a l) d l p y a e e mple in wh ch de tr ct e j t t le o m y be ec d ry to nerve d m ge S LEPROSY

Ma y sy tem d e es of unknown or ite dif f t t ol gy may pr d e me form f rth it s j t t d g at n Hem phil a h red tary blo d d o d crom g ly a e do rine dysfunc t n d Ray a d s d e e a di ea e f bl od ves l a mpl wh h di t the d ty

Lo l d t rb e e th p cific r n n pe fi m y l l d t j i t l ement The e incl de b t t n yn ti formati n of y t in the y m d th r co d ti

T m s f j t t a e us ally b gn chon d m fibr m d l p ma but th m l g ant y o o r m not e

Rh m ti m p fi p ed mina tly l y i m wh h l des l c l p i a d t de e s M t a se ch c inflamm t s r mildly gre v d g t nd many when esti g t d fall to one of th



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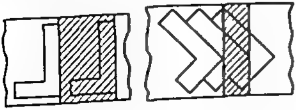

Fig 6 Blank layout comparing amount of material used to produce one block (shaded portion) by two different die positions

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\ rth Temperate zo e h t al o r Central America o th Ame ca trop l A a J a and New Cuine Th y are decid s mo oec o tree l rui th altern te pt t ly comp d ar mat c es. The fl rs ha e a p m t perianth a d h t m ate fl wers a bo n catkin In m t pec es of h k ry (*Carya*) and walnut (*J glans*) h f u t r a drupel ke n t h dehi cent or deh ce t leathery or fibr t s hu k Econ m cally hese trees ar mpo t t b c u tl y upply valu ble timb nd n t g del fla r *See* HICKORY WALNUT s e *lso* DICOTYLEDONEAE EMB YOPHYTA PLANT KI GDOM TREE

[P D S]

Junco

A y f everal pec es of N rth Am a p r w f th gen s *J co* f mily F g llidae Tl e e d are m ll th th E gl h pa w are rith t tr k r t ip and a e predomi t l gray bo e nd l ht g y to wl ıtı h bel w Some pecies h bl ck he d th s gra he ds ome t m ked th r sty red n th back th by i p k b d l g th de j t bel w the w g They r all ea ly gniz d by the d t n tly h t m t l f th wh h th y flash fl ght f n oes est n th rth rn p t f the North Am n e nt t d uthw d the m n n d t n the e tr l d so ther tate d M x c They a comm ly called wh d S PA SERIFORMES

[J D B]

Junction diode

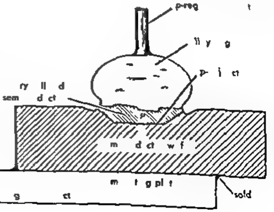
A sem du t ectify g dev e wh ch es tl s m bet e tw r g f pp it e nd n ty type t p odu e th rect fi t The de es a u ed t mp t s ad d t le bru hles g n t r b tt ry h ge d le t o- hem al p oces es q g h gh d e t nd lo l g The l e p w it e all lled sem d t d odes d the h ghe p e n t ll lled m d t r e tifier F d e n of d t ty t pe rr a d mp ties SE MICO D CTO J t d od l fied by th m thod of p p at of th j t d by th m d t m te al A p rt l f t f g m um typ s l d g ld b d d ll y f d j ct n d gr jun t n S l typ al m m w e bo ded t l m n m ll y j t g w j l n, and d ff d j t In g m m t g ld bo ded t pes d f l w p w nd d m ll y types ed f h gh p we p l t Th f w g rm m g j tt d ff ed j t n t pes l l t th d ffi cult f m th g th th rm l p n of th l n l tt th m ll y h led t a w d po l n j t d odes m l m d l l m m ll y bo d La l typ d ly f g y th all y l d ff f p t es t th l d l f m the g ph g g th j t n d n y t l p p t

Fabrication methods G l l l ded germanium d d ar made l y prepar g mall wafer of typ g rmani m about 40 mil n a d and 15 m l tl k After etching each wafer t ld red t m t l pedestal A mall g ld gallium all y wire w lded t a ec d p l tal Tl e free end of tl e g ld w r i the pl c l gai t tl urfa e f tl germani m waf r nd l nded (w lded) w th a p l e f c rre t D ri g tl w ld ng perati n me germani m i d l d l y th g ld and upon c ling reer stallize n tl f e l the i nd l d germanium Thi reery t ll ed regi n (F g l) i *p* type beca at c t in m f th galli m mp rity f tl e g ld w r The juncti n r barrier f th devi i tl e bo da y l tween tl e reery tall zed *p*-typ r gi n d the undi l ed typ y tal

F ed l iminum w r lic n d odes are f l ri ted t a m and witl a re ult y imilar t g ld l nded germ ni m di d Tl e n s gnif ant differe i that tl bo ding p ati t carri d t l y l eat g tl e entir a eml ly rath r tha by lectri l pul ing

The higl p wer g ma m um t l ave all y ju t wh h t f a l dary between a reery tall ed ll y *p* type r gi n d tl *n* typ mat r l f th g nal ry tal ju t in the g ld bo ded u t The d ffe en her i th t th all y u ually i di m inst d of g ld galli m a d the a e f the rec yst ll ed r gi is of the o d r of 1 m rathe th 10 cm Th fu n p oces carr ed t n f tra e d the y t l i m ted aft ward

The h gher p wer s l con unit ar m de by f t n f ery thi ti al m m all y on on ur f ce f a il n w fer d lat r m t ti g w th ti ld Th j t n i tl typ cal ll y j n ti n lth gh the rec y tall ed eg n i e t mely th n A ec d m thod f m ki g h gh p we l n t t d ff e uit bl *p* type mpur ty apor t th rf e f a w fer f t p s l c n The mp ty apo i ually swept th w fer by a t d l fl w g g s After the mp rity h p t t d th w fer t a ffi t d pth to pr d a good p j ct n th w f i moved



Fg 1 S t f b d d f d

Other relatively rare forms of arthropathy are occasionally encountered See GONORRHEA HYPERSENSITIVITY PNEUMOCOCCUS RHEUMATIC FEVER STREPTOCOCCUS SYPHILIS TUBERCULOSIS URIC ACID [F C ST]

Joint (mechanical)

The surface at which two or more mechanical or *structural components* are united Whenever parts of a machine or structure are brought together and *fastened into position a joint is formed* (*see* STRUCTURAL CONNECTIONS) Mechanical joints can be fabricated by a great variety of methods but all can be classified into two general types temporary (screw snap or clamp for example) and permanent (brazed welded or riveted for example) The list that follows is not exhaustive but does include many of the more common methods of forming joints

1 Screw threads Bolt and nut machine screw and nut machine screw into tapped hole threaded parts (rod pipe) self tapping screw lockscrew studs with nuts threaded inserts coiled wire inserts drive screws *See* BOLT BOLTED JOINT NUT SCREW SCREW FASTENER WASHER

2 Rivets Solid hollow explosive and other blind side types *See* RIVET RIVETED JOINT

3 Welding *See* WELDED JOINT WELDING AND CUTTING OF METALS

4 Soldering *See* SOLDERING

5 Brazing *See* BRAZING

6 Adhesive *See* ADHESIVE ASPHALT AND ASPHALTITE EPOXY RESIN GLUE MUCILAGE

7 Friction held Nails dowels pins clamps clips keys shrink and press fits

8 Interlocking Twisted tabs snap ring twisted wire crimp

9 Other Peening staking wiring stapling retaining rings magnetic Also pipe joints are made with screw threads couplings caulking and by *welding or brazing masonry joints are made with* cement mortar [W H C]

Joule

A unit of energy or work in the meter kilogram second (mks) system of units being equal to the work done by a force of magnitude 1 newton when the point at which the force is applied is displaced 1 meter in the direction *of the force Joule is a short* name for newton meter of energy or work and hence is equivalent to 10 ergs and also to 1 watt sec The present accepted relation between the 15 calorie and the joule is 1 cal₁₅ = *4 1855 ± 0 0004* joules The term joule should never be used as a synonym for newton meter of torque" *See* WORK *see also* UNITS SYSTEMS OF [D F R]

Joule s law

A quantitative relationship between the quantity of *heat* produced in a conductor and an electric current flowing through it *As experimentally* determined and announced by J P Joule the law states that when a current of voltaic electricity is propagated along a metallic conductor the heat evolved in a given time is proportional to the resistance of the conductor multiplied by the square of the electric intensity Today the law would be stated as $H = RI^2$ where H is rate of evolution of heat in watts the unit of heat being the joule R is resistance in ohms and I is current in amperes This statement is more general than the one sometimes given that specifies that R be independent of I Also it is now known that the application of the *law is not limited to metallic conductors*

Although Joule s discovery of the law was based on experimental work it can be deduced rather easily for the special case of steady conditions of current and temperature As a current flows through a conductor one would expect the observed heat output to be accompanied by a loss in potential energy of the moving charges that constitute the current This loss would result in a descending potential gradient along the conductor in the direction of the current flow as usually defined If E is the total *potential drop this loss by definition* is equal to E in joules for every coulomb of charge that traverses the conductor The loss conceivably might appear as heat as a change in the internal energy of the conductor as work done on the environment or as some combination of these The second is ruled out however because the temperature is constant and no physical or chemical change in a conductor as a result of current flow has ever been detected The third is ruled out by hypothesis leaving only the generation of heat *Therefore* $H = EI$ in joules per second or watts By definition $R = E/I$ a ratio which has positive varying value Elimination of E between these two equations gives

$$H = RI^2 \tag{1}$$

which is Joule s law as stated above If I changes to a new steady value I' R to R' and H to H' then $H' = R'I'^2$ as before The simplest case occurs where R is independent of I (*see* OHM S LAW) If the current is varying the resulting variation in temperature and internal energy undoubtedly exist and strictly speaking should be allowed for in the theory Yet in all but the most exceptional case any correction would be negligible

This phenomenon is irreversible in the sense that *a reversal of the current will not reverse the* outflow of heat a feature of paramount importance in many problems in physics and engineering Thus the heat evolved by an alternating current is found *by taking the time average* of both sides of Eq (1) Incidentally the change in internal energy if this were included in the theory would average to zero Hence this equation continues to have a similar form $\overline{H} = R\overline{I^2}$ for alternating current application *See* HEATING ELECTRIC [L C H]

Juglandales

An order of the plant subclass Dicotyledoneae consisting of one family (Juglandaceae) with 6 genera including 60 species occurring principally in the

ar cre ted by th captu f lectrons by acceptor mp ty at ms wh ch rema n as fixed n g ti ely charged ent r In both a s the space h rge of n ed imp ty e te ne tralized by tl e p ha ge of the maj r ty carrie

At a p- j nct the ba rier that keeps m jo ty m rs way con t of a dipol l yer f ha ged imp ity ce t rs it e n the type id and g t o the p-typ id Wh n a r e e bia i ppl ed th b rie light increa and req ire m e harg in the d p le laye to produ e the r qui ed tep ltage In order t achie e thi th l er mu t w d n tn e the n ed impu t a e in fixed p tio m the ry t l A the layer widens th cap ta c of the ju ti n d r a es m e th plates of the capac tor are farthe apart The ef e p n ju t on cts a a able capac tan e s w ll ar able res ta c S e VARACTOR

Junct on d ode characteristics Figure 2 hows t p l rect fi t o sw th g d ap cit c chs t ri t f a junct n d de From the recti fi ati ha t i t (Fig 2a) it can be en th t l its sh w much l we rev r e leak ge rre ts nd high ltage bre kd wns C ma m n t how l f rw rd b as ltage dr p t a g e rrent den ty S li n u t an be oper ted p to 200 C h le germ nium unit mu t be ope ted b l w 100 C.

F swit h n p po t n and t rn-off time a e m t p rt nt (e Fig b) The t rn t m f d od g rned by t j nct n capa tan d ll qu t f t Th t rn-off t me u ually the mu l h a te t r g v rned by th t me r qu ed t r mo e ll f the ess m n rity ar n rs j cted t b th th n d p-regi du t g th t m th d od w the f rward b st t Th t all d th mi sty rr er sto g effe t nd t f th der f f w m o eco d f good w t h d od s S l e d odes a lly som wh t s p r t g rmani m n t th re pect F furth d s of th p p rties t p ju cti n e JUNCTION TRA SISTOR TRAN SI O s al POI T CO TACT DIODE [L P HL]

Junction transistor

A t a t r wh h the m tte d olle to b n rs e f rmed betw n sem nd to g s f oppo it duct v ty typ Thi typ of t n st r by f r th m t w d ly s d Ju t n tr sto s r ge in pow r at f m f w m lliw tt (mw) t bo t 30 watt j c toff f qu cy f m 0 5–700 m g y l s (M) nd i g n f m 10–50 dec b ls (db) G rm n m i th m t wid ly ed emi d t mat i l alth ugh l s d for high ltag o high t mp at e appl t o In g n l j t t t appli ble t any el ct ampl fi ati d te t n or wit h ng p obl m n t r qu p t n bo 200 C, 300 volts, o 00 Mc N t ll th se l mit n be a h ed in o devi of ou

J t t tor e la ified by the mbe nd rder of the r gi ns f d ff r t c d ct vity

type by the meth od f fab r cating tl e tructure and s metimes by th princip le of op rat n

Alloy junction transistors Al-o calle l fu ed juncti n t an i tor thes are mad in th p-n p and p n f rm The m tt r and c ll t r reg ns a e formed by recry tall zati f s mi ndu t r material fr m an all y of em co d t m terial di l ed n me su tal le met l mixt r F r the germanium p- p all y juncti n tran t r tl e met l is u ually indium with a mall per entage f gall im F r th ge manium n p-n all y j nct n t an i t r th m tal may be m xture ch a l ad with antim y r b m th with r e i The maj r m tal f ch of the all y (d um l ad r bi muth) ers a the s l ent f r g mani m The mi or lement serves a a ur e of the imp r ty n eded t render tl e ecrystall zed germanium op po te i e nd ti ty type to the rig nal wafer The p n p ll y unit is th m r comm n type F r a gen ral descr pt n and def tion f th term ed h re e TRA SISTOR

F gure 1 e mp res seve al transi t r profiles which how h w the impurity e nt nt ar es thr gh the stru t e In the e pr file C i the c n e tra tion f the p-type impurity a d C is the c n n tration of th n type imp rity The net mpurity cont t d term the c ndu ti ity type and mag nitud (s SE ICONDUCTOR) The profile f the alloy t i t r sh ws th t th r i an ab upt ch ge f impu ty c trat n at the mitter d collector j ncti n and th t the condu t t of the emitte and llecto reg n i theref re high n mpa ed t that of the b e reg o Su h true sh w good mitte j t on efficiency but only mode te c lle t r ltag t g a d el ti ly high llect r p tan e

Grown junction transistors Th ar mad i the p- p and n p n f rms a w ll a n m re om pl cated f rm Th are e eral ariati n f the grown ju ct n t h q The s mplest o sts of c es v ly dding d ff t typ f mpurities t th m lt f m wh ch the m nductor cry t l is being gr wn A s m nd t crystal is u ually gr wn by d pp g the nd f a seed ry tal i to molte em co d ct d by r gi g the th erm l g di ts that n w m condu to s lid fies on the e d f th ed s t fowl w thdrawn Th l d liq d nt f ght pla e pe pe dic t th a s f w thd aw l A p- p str tur be g wn by tart w th a p type melt by add ng at ne po t i th crystal gr wth en gh type mp rity to g light e o th p type mp ty gi ally pr nt nd aft g with h t ued f r a f w m r s by add g a e c s f p-typ mp ty to the melt Th l t g wn eg n w ll be th m tt r r g on a d the g l p-typ ry tal w ll be th c llect r gi n Th impu ty pr fil of s ch tr t re is h wn n Fig 1b Th h gh-c nd t v ty m tt r g n g e a good nje tion ffic e y a d th j n t n b tw e the b a d colle t r gi s i g d al e gh that th unit will how r l t ely l w

from the diffusion furnace and one surface is lapped and etched to remove the p type layer and expose the n type material for the n region contact

Junction rectification Rectification occurs in a semiconductor wherever there is a relatively abrupt change of conductivity type In any semiconductor the product of the concentrations of the majority and minority current carriers is a temperature dependent equilibrium constant The conductivity is proportional to the majority carrier concentration and inversely proportional to the minority carrier concentration When a p n junction is reverse biased (p region negative with respect to n region) the majority carriers are blocked completely by the barrier and only the minority carriers can flow under the barrier This minority carrier current is the sum of the individual currents from the n and p regions and each component is inversely proportional to the conductivity of its region In germanium of about 10 ohm cm resistivity a p n junction reverse leakage current is about 10^{-5} amp/cm² In silicon of the same resistivity it is about 10^{-7} amp/cm² because of the much lower equilibrium constant of silicon.

When a p n junction is forward biased (p region positive with respect to the n region) the majority hole and electron distributions can flow into the opposite region since the barrier is markedly lowered Since electrons flowing into a p region or holes flowing into an n region represent a great increase in minority carrier concentration the thermodynamic equilibrium of the holes and electrons is disturbed and the product of their concentrations increases as the junction is approached The resistivity of both the n and p type regions is considerably lowered by these excess minority carriers and the forward current is greater than the current through a geometrically equivalent bar of material containing no p n junction

The electrons in an n type semiconductor are given up to the conduction process by donor impurity atoms which remain as fixed positively charged centers Similarly the holes of a p region

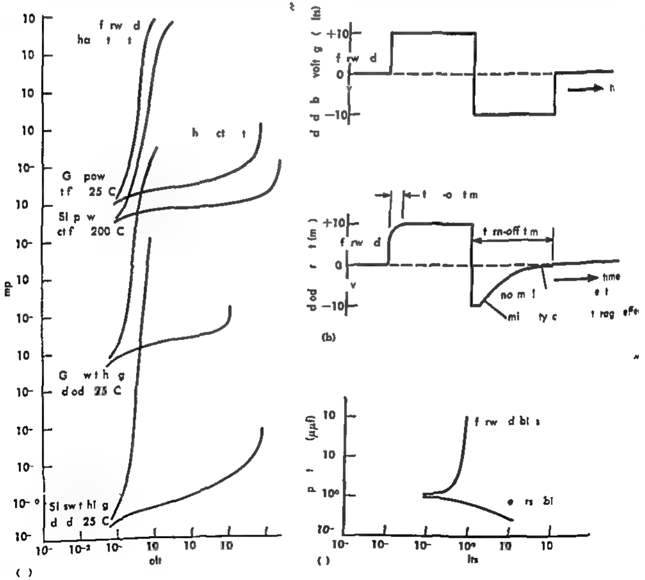


Fig 2 Junction diode characteristics (a) Diode rectification characteristics (b) Diode switching characteristics (c) Silicon switching diode capacitance

c ated by th e ptu e f electro by a cept r impurity atom whi h remain a fi ed n gat ely harged ent In both c es the pa e cha ge f th i ed impu ty centers n tr liz d by the pa charge f the maj r ty c rr rs

At a p n j t n the bar er that ke ps maj r ty carr rs away co ts of dip le lay r f charged imp ty te p t th typ ide nd g t on th p-type side When reve e b as ppl d the barr r he ght i e a es and qu re ha ge n the d p le l y r t p du the re qu ed t p i ltage In rde t achie e th the l er m t wide since th zed impurit es are i fix d po it the cry tal As the lay r de s, the c pa ita of the ju ti n d re s nce the pl t f the c pacit r are farther apa t The ef e a p j t on acts as a a able ap i ta ea ell s a ari bl esi t nce S e VARACTOR

Junction diode characteristics F gure 2 h ws t p al ect fi ation, swit hi g nd ap ta har te i t cs of a juncti n d de From the r t fi atio ch teri t c (Fig 2*a*) it can b see th t a l n un t li w m ch l w r rev r e l akage currents a d h gh lt ge b e kd wn Germ n m ts h w l we f rward bia oltag drops t n urr t de ty S l c n t ca be op ated p t 200 C l le g rm ni m n ts m t be p ated bel w 100 C

F t hi g p po es turn-on nd t rn-off times are m t imp rta t (ee F g 2*b*) The t rn-on t me f d ode g rn d ky its ju ct capacit e a d s lly qu t *l t The tu n-off t m* su lly th rte l h t *t c is g erned by the t m* r qu ed t r mo e ll f the e cess m ty car ners injected to both the a d *p*-regi dur i g th t me the d d w s in th *forward* b tate Th e lled th mi o ty rrie t age ffect d t i f the der f a few m ros co d f good swit h g d de S i n d odes a u ally somewh t upe t germ m u its in th pect. F f rthe d io f th p pert e *of p-n j n t* JUNCTION TRANSISTOR TRAN SISTOR s al POINT CONTACT DIODE [L.P HU]

Junction transistor

A tr t r h h th em tter a d ll t b re r f rm d betw mi nd cto g ons of ppos t co d ti ity type Th s typ f t an tor by f the m t w dely u ed Jun t t n t s a g po t g f m few m llIwatts (mw) t abo t 30 w tt t ff f q y f om 0 5-700 m g y l s (M) d g n f m 10-50 *dec bels* (db) G rm n m i the m t w dely u ed m c d t m t al altho gh s l n i ed for h gh lt g r h gh temp at e ppl c tio In l ju cti t an to ppl able t a y lectr mpl fi ati d t ct wit h g probl m not equ i g p r t n bo 200 C. 300 volts, r 00 Mc. Not all the l m t c n b ach d in e d i f cour

J n ti n tr to l fied by th numbe a d o der f the r g n f d ffe e t d t ity type by the m thod of fabricating the stru ture and met me l y tl e principle of p rat n

Alloy junction transistors Also call l fu d junction tr n tor these re made i tl e *p n p* and *p n* f rm The emitter a d llect r r gi ns a e f rmed l y recry tall zat f mi nd t r mate al from an all y of emic duct r mat rial di lved in s me su tal l metal mixt re F r the g rmanium *p-n p* all y ju ti n tran i t r the met l i u ually indium with a small perc ntage of gall im F th rman m *p n* ll y j i ti n t an t r the m tal may l a m xtu e s h a lead w th t m ny r l m th w th ar n c The m jor m tal f each f the all y (ind m le d or bismuth) ers a the sol t f *g rmanium* The m r el ment serves as a s rce f the impurity needed to r der tl e r ry tallized g rman m oppo te in nd ti ity typ t th rig l wafer The p p all y unit the more c mmon type For a gen l des r pt n and definit n f the term u ed h re *se* TRANSISTOR

F gure 1 c mpares everal t n i t r p files which show h w the imp rity c t t varies th gh the truct e In these pr f les *C* the o c tra t on of the p-type imp rity and *C* the concen t t on of the *n* typ impurity The net impurity conte t determi es the ducti ity type a d m g nitud (s SE ICONDUCTOR) The pr f le f the all y tra tor show that there is n l pt ch g of impu ty concent at t the em tter and collect j ncti ns d that the cond ti ity of th mitter a d collect g i th f high mpared t that f the b r g S ich a tru tu how good m tt r inject effi y but nly mod rate c ll t lt g rat and rel ti ely h gh lle t r cap cit nc

Grown junction transistors Th re mad i the *p n p* a d *n p* f rm w ll a *in m* e c m pl ated f rm Th e *e er* l var at s f the gr wn j nct on tech qu The s mplest c t of a es i ely add ng d fferent types f imp ities t th melt fr m wl ch the s m c duct crystal i b ng grown A semicond t r cry tal is ally g own by d pp ng tl e e d f a seed cry tal int m lt n m c d ct r a d bv g g th therm l g *ad nt* th t new emi d t l d fes on th d f the ed a *it i l* wl withd wn Th l d l q d t f ce i t ghly pl n perp di lar t th a *of w thdraw l A p n p* t uct e c n be grown by t t g with p type m lt by dd g t ne po *nt* n the cryst l growth n ugh typ mp ity t g e l ght e c s e the *p* typ mp r ty orig n lly p es nt and ft r g wth ha t nued f f w m c by add g of p-typ mp ty to th *m lt The l t* gr wn g n w ll b th mitter nd th g nal p-typ cryst l will be the ll to r gi Th imp r ty p file f s ch str ct re s hown Fig 1*b* Th h gh c duct v ty m tter reg n g g d njecti n effi e a d the ju ct n be tw the ba a d coll t eg n i grad l gh o th t the t w ll h w a lati ely low c ll ct cap ta a d high b a kd n

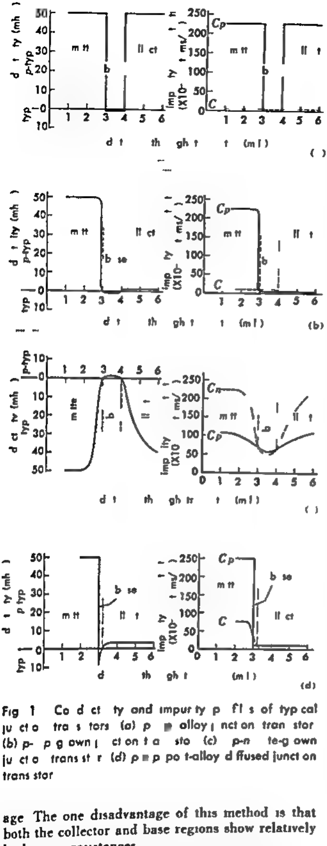


Fig 1 Co d ct ty and impur ty p f l s of typ cal ju ct o tra s tors (a) p ■ alloy j nct on tran stor (b) p- p g own j ct on t a sto (c) p-n te-g own ju ct o trans st r (d) p ■ p po t-alloy d ffused junct on trans stor

age The one disadvantage of this method is that both the collector and base regions show relatively high series resistances

Rate grown and remelt junction transistors These are a subtle variation of the grown junction technique If a melt contains more than one im purity the proportion of each impurity picked up by an ad ancing solid interface will vary with the speed of advance With the proper choice of n and p type impurities one can grow an $n\ p\ n$ tran si tor structure in germanium for example by radically slowing down the pulling (withdrawal) rate for a hort time Sometimes the pulling is actually reversed (hence the terms remelt or melt back) The impurity profile of such a structure is shown in Fig 1c Grown junction techniques are more widely used in fabricating silicon tran i tors than germanium transistors

Diffused base drift transistor In this tran i tor the minority carrier transport across the ba e region is achieved by the effect of a strong electric field built into the transistor structure by a fabrica tion technique called diffused ba ■ In the typical alloy junction transistor (uniform ba e conducti ity) the minority carrier transport acro s the base is achieved by a relatively slow diffu ion process In the drift transi tor the ba e region shows a high conductivity gradient decrea ing from the emitter to the collector (ee Fig 1d) This conductivity gradient means that the majority carrier concentration ■ much greater near the emitter than near the collector In order to cancel the natural diffusion of majority carriers from the high to the low concentration region an electric field must exist of such a polarity as to tend to drive majority carriers back toward the emitter This polarity of field then tends to dri e minorit carriers from the emitter to the collector when normal bias is applied to the device exce s injected minority carriers will be accelerated acro s the base by this field

The method of producing the conductivity gradi ent in the base is usually some sort of olid state impurity diffusion technique One of the mo t u e ful is the formation of an alloy emitter region which contains both n and p type impurities For germa nium the p type impurity is caused to be much in excess and gives a p type recrystallized emitter re gion The n type impurity however ha a much faster rate of diffusion and soon penetrates the original wafer beyond the recrystallization bound ary If the original wafer is p type with ■ relati ely low conducti ity the n type impurity diffu ing out of the recrystallized emitter region ■ in exce near the emitter creating an n type base region with the required conductivity gradient Such a technique as this ■ called by a variety of names diffused base post alloy diffusion pushed out ba e or simply diffu ed

Drift transistors The e show the highe t fre quency cutoff and the fastest switching times of any of the junction transist rs Typically they ha e good collector voltage ratings and low collect r capacitance l ecause of the graded nature of the colle tor juncti n The emitters h wever can with stand only 4–5 olts of reverse bias and show a high capacitance which often limit the frequency re ponse of the de ice

P N I P junction transistors The e tran i tors are intended for high freq iency operati n They minimize ba e transit time by making the l a e un usually thin and they reduce c llect r capacitan ■ by making the olle t r junction unusually thick This ■ accompli hed l y in erting an intrin ic re gion (i region) betwe n the l a e and collector regions An i region i ne in which the net number

of imp ties (minu p) ery low and hence the d ti ity ry low The frequency range f ch tr t r i n t h gh that f d ft tran t s, b t t h gher than that of alloy tran t rs. Both and p p types exi t

Tetrode transistor Th t t h s tw hm t cts on opp site sides f the base r g n If the mitter is b ed w th rel t n t one of the e co t ts a d th the base c t ct g dc b f the m p l ty as the emitter b r of gre t r m gn t de t p ble to limit the f rw d bia ed ea f the em tter junctio t a m ll g o ear th first b ntact Since min ty c ers g es e t ally straight a th base t the llect th w ll al l m t the l m f the b l ed t a reg n close t the fi st b se t ct. Th l w rs the ba e e resista and th ref e cr a. the freq cy resp f th dev ce Th p p rt n of jected ers l t to th base hil m tr n t t th llector h w ev is incr d Th l wer th curr t gai of the dev e

Power transistors The e e u d in th tp t tag f a lect o c cu t both s w tches d mpl fie (CONTROLLED RECTIFIER) Depending o the l d, high lt g r ting a h gh rre t at g h h pow rat g m y be required W th a y f the he t d pat n w th n th d e is a n l mit t F g e 2 h ws th n t on f gr ded em tte -curr t ga with emitt c rre t f typ cal p-n-p j tio pow r tran ist F m th urve t an b se th t a high rre t t g s bt ed t rio los f gain Act lly the Il t at d d p n g i a functi n f c rr t de ty so that tech l g l imp m nts ll wi g l g em tter nd llect c nta ts w ll g e tly impr e the h gh urr t p rf rm Usu lly l ge- ea em tt r and llect r t ts atte d d by ge met cal compl ty poo qual ty j n t s r both S l

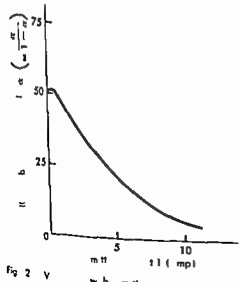


Fig 2 V w h mitt t f mm m rr t g (ll y p w t t

c n offe great p om e t the power tran i t r field b cau e it c pabl of higher temperature operation a d co der bly h gher ltage rating These ad a tag a e ff et by it mor d ffi ult technology a d by the r lat ly large lt ge dr p of silicon t a t high saturation cur rent

Summary The followi g ompari n may be made f the different ju t n tran i t r types Germanium all y t an i tor are u ed in the a d o-fr q cy field a d t a lesser exte t in the power field a d in the mod ate-speed switching field Their e f f equenc ra ges from 50 kc for me of the p wer types t 0 M f som f the sw t h ing types Power r t ng ge from 100 mw t 30 watts a d oltage ratings re 0-150 v lt Silico diff ised j ction grow junct n types h w appr bly h gher volt ge a d power rating (300 lt and 50 watt) l ut h e low frequen y a d curre t rati g In the h gh f q ie y fi ld th drift t ansi t m t u ed G rma um drift tr n i tor r nge p t 400 M in freque cy cutoff and h e abo t 50 mw p w r rat g Silic n d ift tra tor ang p to bout 00 Mc i freque cy utoff I gen l m t sil on t n tor will operate up t 200 C, wh le rma um tr n i tor m t be k pt b l w 100 C [L.P.H.U.]

Bibl g aphy L. P H ter *Ha db k of Sem c d t Elect cs* 1956

Jupiter

The la ge t plan t i the l r system a d the fifth the rd of d sta ce to the Sun It i i ble t th naked ye x pt fo sh rt per od whe t i nea its nj ct n w th the S U ally t i th ec d bright t pla et in the ky O ly M s at it ma m m lum no ity a d V n pp b ighter Jup ter s h ight tha S i the br ghtest fi ed st

Planet and its orbit The m i orb tal leme ar a mim j a mean di t nce t Sun f 485×10 mi n ec nt ic ty of 0.048 causi g the d t ce to th S n t vary abo t 47×10 mi betw pe h l n d phel d real rev l ti p i d f 11.86 y m rbit l l city of 8.2 m / e a d h t of b tal pl e t l pt c f 1 3 S PLANET

Th appa ent q t i l d meter of it d k a e f m b t 47 t me n opp t (50″ t p hel c pp t 44 at ph l pp iti n) t 32″ t o j t The p l fl tte i g d to t p d ot t i n ide abl nd i ly det t d by u l n pect o th llipt ty (−)/ = 0.065 whe e i the eq ato i l d s d is th p l r rad Th eq tori l di m t b t 88 00 m a d th pola d mete i 82,800 mi The l m b t 1317 (Ea th = 1) with n e t ty f few p c t The m i ab t 318.4 (E rth = 1) a d s ac u t ly d te m d f m the m t f th f r m j t l lt The m de ty 1.34 g/ m a l w l e t ti of th f m j pl ts th r e p d g alu f the mean l r ti f gr ty

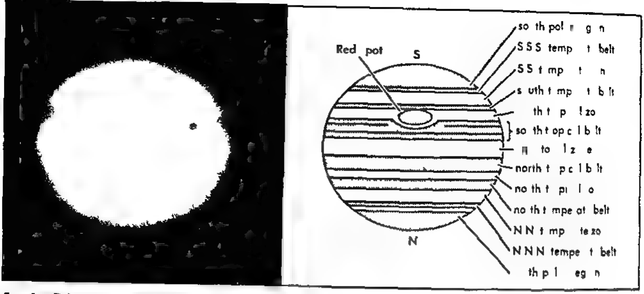


Fig 1 Telescop c appearance of Jup ter and nomenclature of p cipal bands

at the visible surface is about 26 m/sec² however because of the rapid rotation the centrifugal force at the equator amounts to 2 25 m/sec reducing the effective acceleration of gravity to about 24 m/sec²

Phases As an exterior planet Jupiter shows only gibbous phases however because of the large size of the orbit compared to that of Earth the maximum phase angle is only 12 at quadratures and the phase effect shows up only as a slightly in creased darkening of the edge at the terminator The apparent visual magnitude at mean opposition is −2 4 and the corresponding value of the reflectivity (geometrical albedo) is about 0 4 the physical albedo is 0 45 with some uncertainty due to the small range of phase angle observable The high value of the albedo characteristic of the four major planets indicates the presence of a dense cloud laden atmosphere *See* ALBEDO

Telescopic appearance Through an optical telescope Jupiter appears as an elliptical d k strongly darkened near the limb and cro ed by a series of bands parallel to the equator (Fig 1) Even fairly small tele copes show a great deal of complex structure in the bands and disclo e the rapid movement of rotation of the planet The period of rotation determined from long eries of observations of the bands at the central meridian is very short about 9h55m the shortest of the main planets The details observed however do not correspond to the solid body of the planet but to clouds in its atmosphere and the rotation period varies markedly with latitude The nomenclature and mean rotation periods of the main belts of clouds are given in Table 1 The rotation period of any given zone is not exactly constant but ufers continual fluctuations about a mean value O

Table 1 Mean latitudes and rotation periods of J piter s ba ds (after B M Peek)

Band	Reg on	Latitude	Period 9h+	Rema k
North pol r r g on		>+18	55m1	
N N N temper ite belt	Center	+13	55m20	Temporary
N N tempcr te l elt	Center	+38	55m1 s	Temporary
	So th edge	+35	53m55s	
North temperate belt	North edge	+31	56m0 s	
	Center	+27	53m1 s	
	South edge	+ 3	19m0 s	
North t opical zone	Center	+18	55 n 9	
North t op l belt	C nt r	+13	1m09s	Tempo ary
	South edge	+6	0 1	
Equator al zone	Middle	0	50m ls	
South tropical l elt	North lge	−6	50 n (	
	Cer t r	−10	51 n ls	
	South edg	−19	5 m39	
South tropic il zone	C nt r	−23	55 n36	
Great Red Spot	Cent r	−	t 38s	
South temperate belt	No th dge	−	3m0	Tempo n y
	Cer ter	− 9	n 0	
	South edg	−31	m0	
S S temperate zone	Center	−38	[illegible] m0 s	
S S S temperate zone	Cent r	−1	5 m30s	Tempo ry
South polar reg on		<−1	30s	

ation l sh m lt ed atmo phe ic phenomen may depart more strongly from the m a r tatio period of the zone i h h they appear and thus drift p dl w th respect to othe det ils i the zone The ot ti n axi i l ned only 3 to the p rpen di lar to the rbital pl e so that seaso al ef fect a p act ally neglig ble

R d Spot Ap rt fr m the c n ta tly cha ging deta ls f the belts me p rmanent r emiperma ent ma k gs h e b en ob erved t la t fo de des o even ce tur es w th s me fl ctuatio in i b l ty Th most con picuo s d pe manent marking is th g eat Red Spot intermittently recorded sin e th middle of the e tee th cent ry and observed cont uo ly s e 18;8 whe its trik ng redd h c lor ttracted g neral att nti n It co p c s nd m ongly colored aga n i 18 9-188 1893–1894 1903 1907 1911 1914 1919–1920 1926–1927 a d espec lly i 1936–1937 t oth times it h s bee faint and only slightly col ed a d oc on lly nly its tl ne or th t of the bright bay r hollow of the th temp r a e zone wh ch urr ds t h s r ma ned vi ble (see Fig 2)

Th m ot t n per od of the Red Spot between 1831 d 1955 was 9h55m37.5 w th a r nge of natu n of bout ±6 sec. The mean d m io f the Red Spot are about 30 000 m les n lo gi tude nd 10 000 m le in lat tude

Othe ma ki gs An th emark bl miper mane t m rki g the South Tr pi al D tu ban e n interm tte tly b erved n Jup t r between 1901 nd 1935 nd p s bly al o 1940 Th s mark ing e re l ted in th s me one s the Red Sp t, b t with sh rter m n rotation period bo t 9h55m16s a d p riod c lly ame int nj ct n with t. A large numbe f temp ary feat es of h rter d r ti n ha e be n obs rv d but th ir mech ni ms of f rm ti and l w of m ti ns re t unde stood

Th loc t on of p ts the i ble urf ce of J p ter re r rded in tw l ngitude ystem O st m I b ed on a rotat o p riod f 9h50m30 003 s d f r sp t n th eq tori l zo e the her Sy tem II b ed a r t t p od f 9h5 m40 632s u ed fo p t outs d th Th pe iod f tatio of y g spot b g uabl d t e ily q al t th mea p d f e th l g tude sy tem there m a g ner l d ft h h afte a tly l ng t m e ex ed one m mpl te turns that i a x eed 360 Th d ft i l g tud of th Red Sp t with pe t Sy t m II b tw the ye 1831 a d 1955 h n F g 3

Atmosphere Th p c l p t m f J p t r h ct ed by tr b orpt n b ds f meth a CH d mm NH the t mat d qu ti es f the g p t th tm phe bov th l d lay h g f th de of 150 m in thickness at t d rd t mp r t nd p es (STP) d 7 m STP r p t ely Th r t l l t dic t that hyd g nd h l m m t lso be p es t d rect b rv t s of th ult

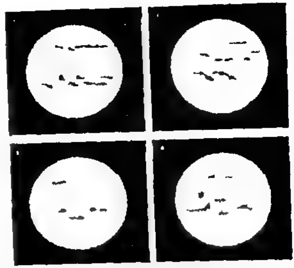


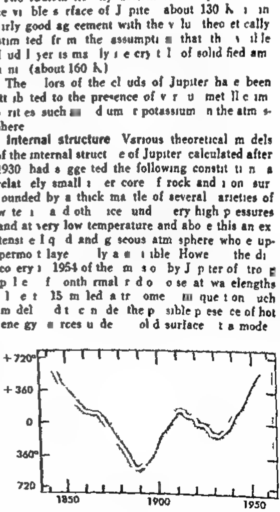
Fig 2 V bl b l ty f the R d Sp t (1) 1929 (2) 1933 (3) 1936 (4) 1938

tion f a star by Jup ter ha e co firmed th c n cl ion

The radiom tri lly determ ned t mperature of the vi ble s rface of J pite about 130 K i in f irly good ag eement with the v lu theo et cally estim ted fr m the assumpti n that th i il le l ud l yer is ma ly i e cry t l of solid fied am m ni (about 160 K)

The lors of the cl uds of Jupiter ha e been att ib ted to the presence of v r u met ll c im p rit es such a d um r potassium n the atm sphere

Internal structure Various theoretical m dels of the internal struct e of Jupiter calculated after 1930 had s gge ted the following constit ti n a relat ely small i er core f rock and i on sur ounded by a thick ma tle of several arieties of w te i a d oth ice und ery high p essures and at very low temperature and abo e this an ex tensi e l q d and g seous atm sphere who e uppermo t laye ly a e i ible Howe the di co ery i 1954 of the m s o by J p ter of tro g p l e f onth rmal r d o o se at wa elengths l e t 15 m led a tr ome n que t on uch m del d t c n de the p sible p ese ce of hot ene gy rces u de ol d surface t a mode



Fg 3 D ft l g t d of th R d Sp t b tw 1840 d 1955 (Aft B M P k)

ate depth below the optically impenetrable cloud cover The recurrence of radio emission in certain longitudes indicates the existence of sources of energy rotating with a constant period of 9h55m29 6s and suggests the presence under the clouds of a solid surface rotating with this period *See* RADIO ASTRONOMY

The existence of an inner solid body at a high temperature appears to be confirmed by measurements of the thermal radio emission of Jupiter at wavelengths shorter than 10 cm which indicate radiation temperatures of the order of 600 K Earlier theoretical models of the internal structure of Jupiter are in need of considerable revision as a result of these discoveries

Satellites Jupiter has 12 known satellites of which the first 4 I Io II Europa III Ganymede *IV Callisto discovered by Galileo in 1610 are by far the most important The main elements of the* 12 satellites are given in Table 2

The four Galilean satellites are of fifth and sixth stellar magnitude and would be visible to the naked eye if they were not so close to the much brighter parent planet All the others are faint telescopic objects The fifth satellite discovered visually by E E Barnard in 1892 moves inside the orbit of Io the others move in much larger orbits outside that of Callisto and have been discovered photographically since 1900

The mas es of the major satellites can be roughly estimated from their mutual perturbations in terms of the mass of the Moon as a unit the mass of III is about 2 of I about 1 of IV about ⅓ and of II about ⅔ The four Galilean satellites show measurable disks easily seen with telescopes of 6 to 8 in aperture larger telescopes show distinct markings on the disks (Fig 4) The apparent diameters are of the order of 1–2 and the corresponding linear diameters are listed in Table 2 Ganymede and Callisto are larger than Mercury but smaller than Mars their densities about 2 5–3 g/cm³ *are approximately the same as the density* of the Moon and of the Earth s cru t Observations of their surface marking and the regular aria tions of brightne s as they move along their orbits indicate that the four major satellites (and

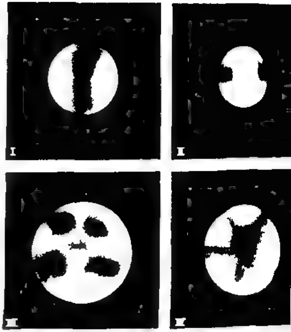


Fig 4 Telescop c aspects of the Gal le n satell t

Fig 5 S tell te phenomena

probably also V) always present the same face th Jupiter much as the Moon does to the Earth th is their periods of rotation are equal to their p riods of revolution The albedoes for I II a III are relatively high however IV is very da and has an albedo maller than that of the Moon

The planes of the orbits of the major satellit are inclined less than 0 5 to the equatorial pla *of Jupiter n that with the occasi* nal excepti of IV they are eclipsed in Jupiter shadow each revolution and al o project their shado s Jupiter and tran it in front of its di k near c njun ti n The eclip es transits and occultati n

Table 2 *Satellites of Jupiter*

Satell t	M n di tance fro n J ipiter 10 miles	Si l real pe od l ıy	Diam t r ı il	M g tu l me n ı po itio	All l (ı ı l)	M (Moon =
I Io	6	1 769	300	(ı)	0 3	1 0
II Europa	417	3 5 1	19 0	5 (ı)	0 3)	0 6
III Ganymede	666	155	3 00	1 ( )	0 0	1
IV Callisto	1 1 0	16 (8)	3 00	6 3 ( )	0 03	1
V	113	0 498	1 0	13 0 (vı)		
VI	7 1 0	0 6	100	13 (ı)		
VII	90	_ 9 (	3	17 0 (ı l t)		
VIII	14 600	3)	3	1 0 (ı l t)		
IX	14 00	8	1	18 ((ı l t)		
X	300	(0	1	18 8 (ı l t)		
XI	14 000	00	19	18 1 (ı l t)		
XII	13 000	6_	14	18) (ı l t)		

J piter s tellites (F g 5) led t the d co ery of the fi te veloc ty of p pagatio of light by O Roemer in 1675 *S* e ECLIPSE ASTRONO IICAL OCCULTATIO TRANSIT (ASTRONO IY) The very small o ter t ll t s of J piter may be c pt d astero d the b t are bje t t l perturba tion b th S and it is possible that at lea t the more di ta t es m y b l t by the pl et t some f t e tim

[C D V]

B bl g phy W M Peek *The Pla t Jupiter* 1958.

Jurassic

Th i m f rock d po ited d ring the middle p rt f the Mesozo c Era. The Jura y tem rm ll u de l n by the Tr a d o erlai by the Cretaceo ystem It w named aft r the J M ta n S it l d a d i its mai ly f ed me t ry ock V l nic ocks are rest ted t rt n regi p rt l rly the N rth Americ Co dll a Th d at n of the J e P r d b h d d bo t 127 000 000 ye s ag esti m ted t be abo t 25 000 000 y

PRE CAMBRIAN		PALEOZOIC							MESOZOIC			CENOZOIC	
A EO OIC (EA ECAM AN)	OTE O O C (LATE P ECAM AN)	CAMBRIAN	ORDOVICIAN	SILURIAN	DEVONIAN	CARBON IFEROUS		PERMIAN	TRIASSIC	JURASSIC	CRETACEOUS	TERTIARY	QUATERNARY
						MI I ippi	P yl						

Subdivision Th Ju e sy tem co st f the ma di m th Low M ddl nd Uppe J Li s, D gg r and M lm Bla k B wn d Wh t J th term appl ed t these d n m c t i pa ti l ly Germ ny F r ubd i t ge (hr t at gr ph u ts) and e (b t at g ph u t) a e b d m ly on th th e t E ope ta d rd ti n The H tta g S m ri Pl en bach a d T r n st ge f m the Lowe J a c th B joci n d B th n a f m th M ddl Ju d th Call i O f d K mm dg n P t l d an d P be k f rm th Upp J I some unt the C ll an l d d the M ddl J Up t th K mm dg an th tag m e in wo ld w de u e b t d t e- g l d g t t n f th f u n the yo g J oth t g m ha e be tr d d f these b ds, f mpl V lgi n R a d th A t a d T th i n M d t r eg Th t ges gr p i l e wh h b ed rta pec es f mm t (d Amm n d f Cephal pod) ha t t of t bed d t m ny se f w ld w de d t but *S* CE HALO DA F S ILS

The n rthwe t European standard section is now bd ded int 58 amm nite z ne Local faunal d ff n t ati n ha e resulted in separat z ne e- quence f r e t egions and ome zo es may be ba ed on fo l ther than ammon t s f r e ample the pelecypod *Buchia* (*Auc ll*) in the Up- pe Ju a ic *S e* PELECYPODA FOSSILS

Oth r ubdi i n of the syst m are formati ns mainly defined by l th l gy wh h f rm the l a i f geologic l mapping In North America f rma t n names e exten ely u ed In Gre t Brita n format name such as Lias I feri r O lite Cornbra h Oxf rd Clay a d ther a e in u e and a me of the e r ck units traceable t other count e th me n me ha e bee appl d The ge of f rmat n name for mappi g ha great ad a tage h we r w ld wide correl tio are b ed o tage and z e

Paleogeography Ma y autho ities deny the f mer e i te e of l ge tine t a d la d bridges the region f pre ent-d y oce s with s me ex cept n I tead a rel ti e permane cy f o ean a d c t ent is n w wid ly cepted During the Jur ic the Pa fic the N rth Atla tic the So n d and the A ct cea s we e in xi tence The N rth Atl tic d Scand a were pr bably ep rated fr m on n ther by a l nd br dge ext nding f m Sc tla d t I ela d d Gre nla d A there e n kn wn mar e Jura ic deposit n either s d f the S th Atla ti th ex st nce of an Af r n B il n nt ent th t f rmed th western h lf f G dw n l nd m y still be co sidered a Th ea t rn h lf of Go dwa la d w n the p e nt-d y I d n Oc which w s pr l bly d y la d d t g the J ra i a d f rmed the Aus t lo-I do-Madag sca c t e t r Lemu ia The west rn d ea tern pa ts of Go dwa al nd wer sep t d f m n a th r by a J a sic ea n the a t s de of Af ic Th m i e depo its of the Jur s o ea a e conce led bel w the floo of th p e t o ea All kn wn mari e Ju assic de p s t oc in p rt of the ti e w wher they w e dep it d n comp rati ely h ll w w t The s h rdly gle ep i ic (h ll w nl d) se wh ch r ma d n n nd the sam reg o thr gh ut all f the i m ted 25 000 000 years of the J r s Per d The dur i n of the J r i m r t a g es s s d p dent th ch r t f th p rt of the ont t whi h wa flood d St bl h l es h a tho the E pe p rt of Ru g lly ha e f ly thi d n om pl t of J r s c d me ts wh as l s st bl hel e h th n n rthw t E rop ha e der bly thi k d p it

G t th es of s d me t we c umulat d th geo yn l al reg ns, a f ex mple th Ame C d ll r wh h f rm d p t f th m P fi m b le b lt. A the m b le b lt the T thy t ded f m th Med t rr ne n t Pe the H m l y s a d I d s a S h ge sy cl were r p dly d e t n ly s k g t gh Th f th q ally f t r g rr und ng l d m d t q ntit e f ed ment ailabl

for filling them In spite of their rapid sinking the depths of these geosynclinal seas were not (with some exceptions) considerably greater than those of the more stable areas as the speed of sinking was compensated by rapid filling Typical shallow water deposits are common in such geosynclinal seas *See* GEOSYNCLINE

The Precambrian shields which form the oldest and most stable parts of the earth s crust were land areas subject to erosion during the Jurassic Period Thus in North America the Canadian Shield was land bordered by seas both to the north and west and the Scandinavian Shield was surrounded by seas in Late Jurassic times (Fig 1) Smaller areas underlain by older rocks such as the Bohemian Mass the French Central Plateau the Belgian Ardennes and the German Hartz Mountains were lands the coastlines of which are indicated in many places by conglomerates and sandstones (Fig 2) *See* PRECAMBRIAN

The faunas of the Early Jurassic particularly the ammonites seem to have been universal and distinct faunal realms can scarcely be recognized for this time During the early part of the Middle Jurassic (middle Bajocian) a Pacific province seems to be indicated and somewhat later in the Jurassic (possibly Callovian) a boreal realm is developed in the Arctic and parts of Russia Its ammonite faunas are clearly distinguished from those of the realm of the Tethys These faunistic differences do not necessarily indicate any differentiation of climate which apparently was very uniform

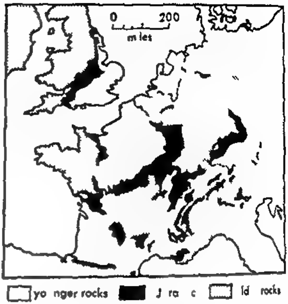


Fig 2 Distribution of Jurassic outcrops in west central Europe (From R C Moore Introduction to Historical Geology 2d ed McGraw Hill 1958)

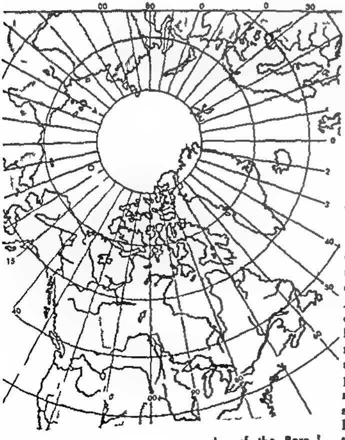


Fig 1 [illegible] paleogeography of the Boreal region

as indicated by the fossil vegetation Jurassic glaciations are unknown

Tectonic history The Jurassic Period was for most parts of the world a time of comparative tectonic passivity diastrophism of a major order and connected with the intrusion of batholiths was restricted to the North American Cordillera Mountain building connected with volcanic activity took place in the Crimea and Caucasus and minor folding and faulting (the so called germano type folding) is known from northwestern Germany and other areas In the North American Cordillera two major episodes of diastrophism are recognized the Agassiz and the Nevadian phases The Agassiz phase took place at the boundary between the Middle and Late Jurassic the Nevadian orogeny at the end of the Jurassic Period While the Agassiz phase seems to be restricted to parts of southern British Columbia the Nevadian phase resulted in the uplift of great parts of the former Cordilleran geosyncline This new land was consequently subjected to erosion and the eroded material was deposited in the east where it contributed to the sediments of the Lower Cretaceous Intrusion of large batholiths in the North American Cordillera and widespread volcanic activity were not restricted to these two episodes of tectonic diastrophism but took place also during part of the Early and particularly Middle Jurassic Germano type folding affected many parts of the world within belts of earlier folding which had not yet become entirely stable Orogenic movements of this type occurred during the Late Triassic and perhaps earliest Jurassic (early Cimmerian phase) The late Cimmerian phase of many regions is about equivalent to the Nevadian orogeny and is subdivided into the Deister phase between the Kimmeridgian and lower Portlandian and the Osterwald phase between the lower and upper Portlandian *See* BATHOLITH

Of utmost importance in the history of the Jurassic Period were the epirogenic movements. They were the main cause of the transgression and regression of the sea, of the opening and closing of seaways, and of the migrations of faunas. They also influenced the rate and character of the sedimentation. See DIASTROPHISM; OROGENY; TECTONIC PATTERNS.

Life of the Jurassic. The Jurassic flora is characterized by ferns, which occur abundantly in certain regions, and by numerous gymnosperms. Among these the cycadeoids (Bennettitales), such as *Turnaptrus, Wilsonia*, and *Pterophyllum*, extinct palmlike plants related to the modern cycads, were dominant. Ginkgos were widely distributed; pines, cedars, and other conifers were abundant. The presence of angiosperms is indicated by pollen grains. Calcareous algae built reefs in some marine areas. The comparatively great uniformity of the Jurassic land plants does not suggest the existence of climatic zones.

Reptiles were represented by a great number of different forms. On the land the dinosaurs were the dominating forms, represented by the orders Saurischia, with hipbones comparable to those of the reptiles, and the Ornithischia, with more birdlike hipbones. Among the Saurischia both small and giant forms were present: *Compsognathus* was about the size of a chicken, while the bipedal carnivorous *Allosaurus* attained gigantic size. *Brontosaurus*, an amphibious four-footed plant eater, reached a length of more than 60 ft. The plant-eating Ornithischia were represented by the bipedal Ornithopoda and the heavily plated quadruped *Stegosaurus*. In the sea *Plesiosaurus* and the fishlike *Ichthyosaurus* and crocodiles such as *Teleosaurus* (up to 20 ft long) were locally abundant. In the air the pterosaurs were represented by *Rhamphorhynchus* and the *Pterodactylus* and the skeletons of the first bird, *Archaeopteryx*, which had reptilian jaws and teeth and strong, clawlike fingers, were found in the Late Jurassic lithographic stones of Solenhofen. Practically all groups of modern fish were present. ... Others of the pre... are represented by forms such as *Gyrodus*, *Lepidotus*, and ... sharks by *Hybodus*. Of the amphibians frogs and toads were present. Both in England and North America ... jaws and teeth of small mammals ... the Mesozoic ...

The most important invertebrates of the ... are the ammonites which developed many ... families and genera unknown in the preceding ... Period. The ... vertical and worldwide ... appearance ... made them the best guide fossils of the ... Other Jurassic cephalopods are belemnites. ... gastropods ... pelecypods ... number of genera such as *Gryphaea*, *Inoceramus*, and *Trigonia* ... important ... for age determinations and correlations. The echinoids are abundant in certain regions, but the crinoids are represented only by a few genera such as *Pentacrinus*. The brachiopods are restricted to a few groups. Siliceous sponges formed reefs locally and lime-secreting hydrozoan colonies were abundant in the Mediterranean region. Corals lived in certain regions at various times during the Jurassic. Land invertebrates are represented by such insects as flies, butterflies, and moths. Among the crustaceans ostracods are known from both marine and fresh-water beds and are used for age determinations. See PALEOBOTANY; PALEONTOLOGY.

Economic products. Iron ores of Jurassic origin are present in Western Europe. Those of Lorraine belong to the Middle Jurassic, whereas those in Britain occur in both the Lower and Upper Jurassic. Coal is present mainly in the Lower Jurassic and the underlying beds of the Rhaetic in many parts of the world, including Arctic regions. Upper Jurassic coal is known from Scotland, the Lofoten Islands, and northeast Greenland. Not all of the Jurassic coal occurrences are workable under present conditions. Highly bituminous rock and oil shale occur in western Europe. Lime and cement are made from calcareous beds in England and Germany, bricks from the clays. Lithographic stone comes from the Upper Jurassic of Solenhofen, Bavaria. Many good building stones come from various beds and are quarried in the Jurassic limestones of western Europe. Petroleum is obtained from various Jurassic horizons in the United States, Canada, Mexico, Brazil, France, Germany, Morocco, and Saudi Arabia. [H.F.]

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Jute

A natural fibe(r) obtained from two Asiatic species, *Corchorus capsularis* and *C. olitorius*, of the plant order Malvales (Fig. 1). These are tall, slender, half-shrubby annuals, 8–12 ft tall (see ANNUAL PLANTS). When harvested the stems are retted in tanks or pools to rot out the softer tissues. The strands of jute fiber, or gunny, are then loosened by beating the stems on the surface of the water. The fibers are not very strong and deteriorate quickly in the presence of moisture, especially salt water. Despite these weaknesses, jute is much used. It is inexpensive and easily spun and converted into coarse fabrics. It is made into gunny, burlap, bagging, sacks for wool, potato sacks, covers for cotton bales, twine, carpets, rugs, cushions, curtains, and as a linoleum base. It is also used in making coarse, cheap fabrics which are only fairly durable. Most of the commercial supply comes from plants grown in the Ganges and Brahmaputra valleys in India. See FIBER CROPS; FIBER, NATURAL; MALVALES.

[P.D.S.]

Fig 1 Jute *Corchorus caps la s (From P DeJa v ll Atlas de Poche des Plantes Ut les d s Pays Chauds L brarie des Sc ences Nat elles 1902)*

Fig 2 (a) D sease les ons on jute stems (b) Roots of jute plant affected by root knot nematodes Da k area on oots are early stages of root dec y

Diseases of jute A number of diseases of jute cause losses in yield and reduce fiber quality Runner and specky fiber are primarily due to disease producing organisms

The fungus *Macrophomina phaseoli* is believed to cause the most serious di ease of the two species of jute It is seed borne and soil borne and pycnidiospores from susceptible plants besides jute also serve as sources of infection The stem leaves and roots of both young and older plants are subject to attack Stem infection usually takes place through a leaf petiole or at a node (Fig 2) Root rot is complicated in that severity is increased when *M phaseoli* is in combination with other fungi bacteria or nematodes such as *Fusarium solani Pseudomonas* sp and *Meloidogyne incognita* respecti ely See BACTERIA FUNGI NEMATODA *see also* LEAF (BOTANY) ROOT (BOTANY) SEED (BOTANY) STEM (BOTANY)

In contrast to *M phaseoli Colletotrichum capsici* causes lesions on the stem internodes and may also attack seedlings and capsules of *C capsularis* See FRUIT (BOTANY) *Macrophoma corchori* and *Diplodia corchori* cause stem diseases Two species of bacteria *Xanthomonas makatae* and *X makatae* var *olitorii* attack the stem and leaves of both *C capsularis* and *C olitorius Pythium splendens* causes a root rot and subsequent wilt of *C capsularis* and indications are that other species of *Pythium* also are root pathogens of jute

Other fungi which attack jute are *Sclerotium rolfsii Curvularia subulata Cercospora corchori, Rhizoctonia solani Helminthosporium* sp and *Alternaria* sp

Seed treatment with an organomercuric material such as Ceresan Granosan or Agrosan GN should be practiced for control of seed borne pathogen and seedling diseases Stem rot may be pre ented by spraying with bordeaux or a colloidal copper compound The exce e use of nitrogenous fertilizers increases the incidence of tem di es es Root rot control requires the u e of crop rotati n and in some areas the u e of recently developed varieties of *C capsularis* which are more tolerant to certain root rot pathogens than *C olitorius* See AGRICULTURAL SCIENCE (PLANT) PLANT DISEASE

[T E R L]

K Kale—Kyanite

Kale

Eth of two cool a b 1 l rucifers (*B s ca l cea a a eph la a d B fimb i ta*) of Medit rr a o ig d bel ng g to th pl nt ord P erale K le i grown for its nutr tiou gree e led le Di ti t e te re produced in Eur pe fo tock feed Kale a d colla d d f fer ly th f rm f the leave b th r minor eg t bles in the Un ted State C ltural pract e a e m l t tho u ed f cabbage b t k le is m t e t h gh temperatu es Strains of th Sc t h d S be n a tie mo t p pul kal s mod tely t ler nt f acid o l M ll ly mea t mpe tur b low 70 F fa be t growth H rve t g i g erally 2 3 months fter pl t ng l g n i an imp rt t p oduc g tate Th t tal an u l farm lu i the United St tes i $740 000 *S e* CA B GE COLLARD PAPAVERALES VEGETA BLE GROWING. [H J C]

Kaliophilite

A m e al t to l e t f nd in o l r ck h gh n pot um nd l w s sil Kal ph l t s e of th ee p lymo ph f rm f KAlSiO th the the r e m r l k l lit and n rtho h mb ph f rmed art fi lly at ab t 500 C. It y tall zes in the hexag al syst m pri m ti ty l f w th poo p i m t c a d b al l ge Th ha d 6 on M h cale a d the p fi gr t 61 At h gh tempe tu s a mplet sol d sol t s ex t bet n KAlSiO and NaAlSiO b t t low t mper t th s s t compl t Th pri p l urr n e f k li ph l te i t M nte Somma Italy *S e* SILICATE MI ERALS [C S HU]

Kalsilite

A ra m l d r l d i 1942 from le i ock t M f ru in so thwest Ug da K l il te b m b nth d It of th thr e polym ph f rm f KAlSiO the th s r k l ph l te nd n orth h mb pha e f rm d t fi l at bo t 500 C. Th m al a h wn by phot ph i h g n l The p fi gr ity 2.59 In d of fra tio and ge al p th t r mbl n ph l d diffi lt t d t gui h f m t St t lly th tw m e al a mil b t b long to d ffer nt try t l l Th k wh h k l l t wa f d h a d k-col ed fi e-g ed m t x w th la g l ry tal d g n h y ll w patche These p t h r t m t m i s f d p d l t d kal il t S FELD ATHOID [C S HU]

Kame

A hill f p o ly tratified and rt d glacial dr ft in or near an e d m ra or interl bat moraine The dep it wer f med i h le or cracks f the gl c r p rtly und r tanding water a h wn by incl ed bedding Melt ng of upporting i e w ll di turbed the b dding Kames are ommonly a oci ted in kn bby gr up with m ll feat r s te m d kettl appare tly l ft from the m lting of l c lly b ed bl ck f gl cial

Kam i W Th m ll oc ot d d p ss m lt t d b of p d g (USGS ph t)

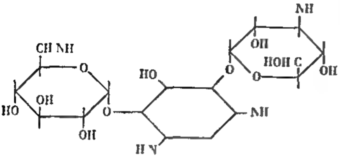
Th term k me ha been u ed l o ly and applied t hills ca d by stream ro i n of o twa h to p tted utwash or t ll d lta M ul kam e t k ng onical gr el fill ngs of le m lted th gh i gn t i e S GLACIATED TERRANE [F T T]

Kanamycin

A ant biotic pr du ed by a p ev ly u de cribed sp c es f t n myc s St pt myces k myc t u d co r d I p by D H m o Umezawa a d w k Coll b ati re ear h by Bri tol Labo t r es the Un t d St tes a d b J pane s nt t d ated u f l ga n t certa n or ga ms h h e e v me i cal probl m Th ncl de t phyl c h h a e e t nt t othe mm ly ed a t b t c the tub cle b c l l s r t t t ept myc n a d i o t n c d h d zid nd me gr m eg tiv g n sm e pon bl f r u i ary t ct fecti n S ANTI BIOT C ISONICOTINIC ACID HYDRAZIDE STRE TO MYCI

Ch mi l t d e f k namy h hown t be ate l bl tabl ba ant b t m

posed of three moieties These are 2 deoxystreptamine (a component of neomycin) 3 glucosamine and 6 glucosamine The latter two components are glycosidically attached to the deoxystreptamine and represent compounds not previously found in natural products



Kanamycin

The antibiotic has bactericidal activity for a wide variety of gram positive gram negative and acid fast bacteria Its antimicrobial spectrum is similar to that of neomycin (*see* NEOMYCIN) Organisms resistant to neomycin are also resistant to kanamycin and vice versa Resistance to kanamycin develops slowly in step wise fashion except for the mycobacteria which develop resistance rapidly

Kanamycin is far less toxic than neomycin both acutely and chronically when given by parenteral route (injected into the body) High dosages given for prolonged times to experimental animals can cause kidney vestibular and auditory damage Intramuscular injections result in high blood levels in one to two hours Kanamycin is also detectable in the cerebrospinal fluid When given orally the low blood levels obtained indicate that the antibiotic is poorly absorbed from the gastrointestinal tract

Clinical responses have been obtained with a variety of infections Staphylococcal infections accompanied by bacteremia (bacteria growing in the blood) have responded as have some urinary tract infections caused by a variety of organisms including *Proteus* Treatment of urinary infections due to *Pseudomonas* has not been as successful Early studies on chronic tuberculosis indicate usefulness when the organism is resistant to streptomycin and isonicotinic acid hydrazide Salmonella and shigella infections have also been treated successfully Kanamycin has been used satisfactorily for preoperative bowel sterilization by oral administration

Decreased auditory acuity (hearing) in the high frequency range has been demonstrated usually only by audiometric measurement Only a small proportion of patients had subjective loss and only rarely did complete deafness occur Decrease in renal function has occurred rarely and was observed to return to normal after stopping treatment [J L]

Kangaroo

Any of several species of Australian marsupial mammal of the family Macropodidae The same family includes the tree kangaroos, musk kangaroos and wallabies Kangaroos are usually large weighing as much as 200 lb and are typically animals of the open country a habitat in which their jumping method of locomotion is frequently developed They have long powerful hind legs, and long muscular tails Their front legs are short and are used for locomotion only when moving about slowly as they graze They feed and travel in pairs in family groups or in large bands

Kangaroo a marsupial

Kangaroos formerly were important as an item of diet in Australia but they have been so severely depleted for their hides which make good leather that they are no longer significant as food animal They compete with domestic stock for the forage on grazing lands and are given little or no protection *See* MARSUPIALIA [J D B]

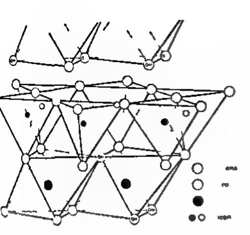
Kaolinite

The principal mineral of the kaolinite group of clay minerals Kaolinite is composed of a single silica tetrahedral sheet and a single alumina octahedral sheet These two units are combined so that a common layer is formed by the tips of the silica tetrahedrons and one layer of the octahedral sheet (Fig 1) *See* CLAY MINERALS

Kaolinite is of fundamental importance in the ceramics industry because of its excellent firing properties and refractoriness It is also used extensively as a filler in rubber products and for coating and filling paper products *See* CERAMIC TECHNOLOGY

Structure In the common structural layer two thirds of the atoms become O instead of OH because they are shared by the silicon and aluminum The aluminum atoms which are present occupy only two-thirds of the possible positions in the octahedral sheet and are hexagonally distributed in a single plane in the center of the sheet All charges within the structural unit are balanced and the formula for kaolinite is $(OH)_8Si_4Al_4O_{10}$ Any replacement within the lattice are of very small magnitude

The sheet units of the kaolinite mineral are continuous in both the *a* and *b* crystallographic direc



g 1 D g mm t k t h f th t ct f th l n l y (F m R E G m Cl y M l gy McG -H ll 1953)

u Th y e tacked one abo e the ther in the d ecti with sup p t f O d OH planes dj c t units These units e h ld firmly to- geth by hydrog b d ng

All kaol ites d t ha e the same order of rys- t llinity Poorly cry tall zed ka l ite re d o d ed l g the b is w th the t l ye randomly d pl d by m lt pl f b /3 The e poorly crys- t lli e v ri tes l h e l ghtly h ghe fi t rder sp c g th th w ll crystall zed mi e l Ka linit is u lly refe ed to a a 7 angstrom cl y min l beca e t fi st der b al pacing s l this app ox mat magn t de D ck t d nacrite altho gh r ely found i cl y material h t c tures im la t k l n t They are comp d f th ame structural n t and d ff only i the sta king of the l yers. The u it ll of d ckite is med p of two k olin te layers The n c te unit ll c mpo ed of unit lay s

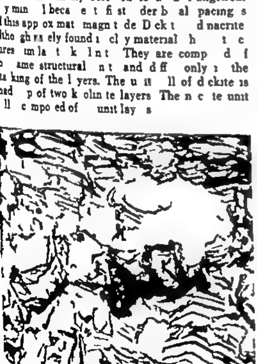


Fig 2 El ct m g ph f k l t Geo g (F m R E G m Cl y M l gy M G w H ll 1953)

Morphology Electron micrographs of well crys- tall ed k olinite show well form d six sided flakes freq ently with an elongation in o e d rection (Fig 2) Part cles w th le s dist nct six sided flake ha e been b erved in p rly crystall zed kaolin ite The latter ha e ragged and irregul r edge and a very crude hexag al outline In ge eral poorly cry talli d kaol nite ccurs in maller par ticle than the well crystallized mine al

D ckite particle are very well fo med and have a disti ct hexag al outl e They d ffer from kao- linite i that they a e much large and can some- t mes be st d ed with a light m roscope

Na it part les are somewhat irregular rou ded fl ke- haped un ts. Some of them show a r de hex gonal outli e

Properties The mineral ka l te has a low cat ion exch nge capacity (5–15 milli quivalents per 100 g m) Broken bo d around the edges of the l ca al mina u t are the major cau e of this exch g apacity Ani n e change capa ity i also low except when t t ral hydroxyl are replaced or the a n is adsorbed because of its epita al fit The rate of the ha ge re ct n i y rapid d th xchange cap city increases a the p ticle si e dec

Kaol nite contains no interlayer w ter betwee the t ll layer It d es h we er h the ability to ads rb wat r and develop pl ticity Thi w t r has a defi ite config atu and is referred t nl q d w te

When kaolinites are heated they beg n to lo e their OH structural water at about 400 C with the dehyd t n b g complete at 550–600 C. The pr t mpe atu e for the l ss of this OH water ie f om kaolinite t kaolinite and may be ex plai ed by variation in particle size and crystal l ity The loss of OH water in poorly crystalli ed kaolinite is acc mp nied by a f irly complete loss of tr ct re but in well cry tallized ka li te s me tru t ral mna t persi t until subjected to h gher tempe t e

A sh rp e thermic re ctio c s at 950 C in ll ly ystall ed kaol te The xpla n for the th rmic r tio h s b n ttr buted t the f m t n f y Al O by ome w k s d to th n cle t n of mullite by the Rece t wo k str gly fa o the l tter pla t n

Formation Th l nite typ f m e l forms d a d cond t at l w t mpe at e nd pr It c n f rm nder hyd th rm l d t thro gh th lt at n f th lay m eral K l te m y f rm fr m y co st tu t f the alk l es a d alk l e e th e r m d s fa t a th y lbe t d f m the p nt rock or f the e m t s d d the t mp t e mod at It a p i pal mp t f late t type l Wh cal um pre e t the e i o m t th f rm to f k l ite i r t ded

Th p e t day m e me t d n t fa th f mat n f k ol t The p ese f a l t m r ed me t i d f k ol n t e a e th m l d not form

in the sea It is also indicative of relatively rapid accumulation of material *See* CLAY COMMERCIAL
[F M W R F G R]

Kapok tree

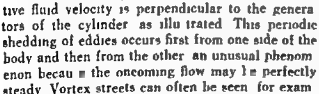
The kapok or silk cotton tree *Ceiba pentandra* is a member of the bombax family (*Bombacaceae*) The tree has a bizarre growth habit and produces pods containing seeds covered with silky hairs called silk cotton It occurs in the American trop

Pods and leaves of kapok tree (*Ceiba pentandra*) (From E L Palmer Fieldbook of Natural History McGraw Hill 1949)

ics Java Philippine Islands and Ceylon The silk cotton is the commercial kapok used for stuffing cushions mattresses and pillows Kapok has a very low specific gravity and is impervious to water consequently it is excellent material for filling life preservers and other similar equipment *See* MALVALES
[P D S]

Karman vortex street

A double row of line vortices in a fluid Under certain conditions a Karman vortex street is shed in the wake of bluff cylindrical bodies when the relative fluid velocity is perpendicular to the generators of the cylinder as illustrated This periodic shedding of eddies occurs first from one side of the body and then from the other an unusual phenomenon because the oncoming flow may be perfectly steady Vortex streets can often be seen for example in rivers downstream of the columns supporting a bridge The streets have been studied most completely for circular cylinders at low subsonic flow speeds Regular perfectly periodic eddy shed



Karman vortex street

ding occurs in the range of Reynolds numbers R based on cylinder diameter from 50–300 Above *Re* of 300 a degree of randomness begins to occ in the shedding and becomes progressively grea as *Re* increases until finally the wake is complete turbulent The highest *Re* at which some slight p riodicity is still present in the turbulent wake about 10^6

Vortex streets can be created by steady win blowing past smoke stacks transmission line bridges missiles about to be launched verti all and pipe lines above ground in the desert Th streets give rise to oscillating lateral forces on th shedding body If the vortex shedding frequency near a natural vibration frequency of the body th resonant response may cause structural damag The Aeolian tones or singing of wires in a wind an example of a forced oscillation due to a vorte street T von Karman showed that an idealized i finitely long vortex street is stable to small distur ance if the spacing of the vortices is such th $h/a = 0.281$ actual spacings are close to this valu A complete and satisfying explanation of the fo mation of vortex streets has however not yet bee given For $10 < Re < 10$ the shedding frequenc f for a circular cylinder in low subsonic speed fl is given closely by $fd/U = 21$ where d is the cyli der diameter and U is stream speed h/a is approx imately 1 7 A Roshko discovered a spanwise p ri odicity of vortex shedding on a circular cylinder $Re = 80$ of about 18 diameters thus it appea that the line vortices are not quite parallel to th cylinder axis *See* FLUID FLOW PRINCIPLES VOR TEX [A E BR

Bibliography A Roshko On the wake and dra of bluff bodies *J Aeronaut Sci* 22(2) 124–13 1955

Karst topography

Characteristic associations of minor third orde destructively developed land features resultin from subaerial and underground solution o limestone under conditions of humid climate Th pattern features are progressively carved int second order structural forms such as plain plateaus or even hilly and mountainous upland containing limestone layers at or near the surface Virtually all limestone formations are products o biological or chemical precipitation of calcium carbonate $CaCO_3$ from aqueous solution The are therefore susceptible in varying degree t resolution in surface and ground waters partic larly when such waters are charged with carbon dioxide CO_2 from vegetative sources or when the waters are under pressure *See* LIMESTONE

Favoring combination of the factors in l ed produce a landscape unlike those resulting from other agents of land sculpture Where a kar t topography has developed most surface water dis appears quickly by entering sinkholes and oth r entrance ways into underground tube passag s and caverns that are enlarging because of th

presence d p ag f the e water M st tr am —ge lly all b t f w t u k t eams m the deeper valleys—are h rt nd c ce ill d fi d ll nd ab ptlv nk or s allow h les The l ck of a rfac t m ystem i re flected in h ll thout th l ne di ide a d in terv ll y h acter of m lly tre m er ded re g ns. Th ame k t is t ken from th regi nal des gn t n f c a t l zone of h ll a d l w moun tai l g the n rthe tern ho e of the Ad i t c Sea In th eg n of l me t e ck the land pe lv e rywh e ch cter d by a pred m n nce f sol t on m de topogr phy

S kh l M d ty K pth t d gro d w t b t 50 ft (U S G l g l S rv y)

Sinkhole types Tw tr ted typ f s nk holes th d l n nd the p may b pr ent *D l* A d l e a c haped l t o m d dep es i n c mm ly c ll d kh le per h p h dred f fe t n d met w th l co ed l pes It gen lly h s n p n entra c t the derg o nd a d u lly doe t d h ge nt an t r bl The b ttom m y be fficı tly l gged with w t t m ta n a p d fo y ar th n may bruptly l ll its w te e b pt d ng lp

P no typ The lly r ult f m l cal f l f a l t n-ch mbe oof wh e llaps p od the f e pon nkhol Th s typ t d t be teeply w ll d mm ly with b r rock, a d l d to a c la ge en gh t h dev l ped t b l ty f r ck Co l e e f h e ll pse p i m y tu lly xp e mo t f th l rme a t th rth f ce w th em nt port f th oof om pl s t l bridge r tu el A f e ll y wh ch by d nce c ed th f x t ng m y ha t t am wall ed d wn by fo mat f a p r d th bec m s king ek lost R t rn f th t m w t t f d g l k ly al g som m j r r lley lt th pp r u g wh h t b d d ntam tnd l ke prı g f filt ed gr d w t

Soil lapiés and shore conditions In a kar t topogr phy much lime t t dis l ed by ra n and l w ter before r ff eache inkholes r streamw ys In oluble t tuent like cl v and grain d cl ert nod le may remain gentler l pe a a c ntinually thi kening co er of re d al l aptly n med t rr s fr m t red e l

Contact f uch l with the derlying lime t e i gener lly harp d may be ery irreg lar be au of varying tr cture i the rock aria tion uppl of water and ar d ol bility of the rock If er n trip off thi l m ntle m ture k t may ome t l ght a luti made urface with r l ef of a few i ches t a few feet th t i k wn a l pi E en withou t a il c e th attack f ra n and ow water can produce a k d f l pi

Sea water ev when atur ted w th $CaCO$ may p odu ragged lap rface on lime tone h re l that are ul ject t c tant wa wa h This may be a r ult f l ght ch nge in temperat re a d pre ure in b eaki g wa e Mar ne alg e w g o t h wa e- wept urf c m v al be a f i g fa t

Related features A kh le- iddled urfa e i n lcareous ock m v lt fr m exten e g nd wate l tio in ubj ce t l m t ne r d lom t Con que t s b id c of the o erlyi g l bl o k t t d pres oc ur with lu ti l mo l Thi mm nly t rmed oluti n b d nc th fill d it es ne er ha ing be n pe a E the p ti l remo al of buried b d f gyps m d k lt m y imil rly p odu a olut al ub de c top graphy

Cyclical landform development The eq n e f h ng i la df m f kar t r g ons from nit a t n f s kh l th ugh tag f th r i cr a mb l gem nt a d ales e c w th col l p f er d e nt l w st ng way of terve ng hill lea s br ad b ttomed lowland (u la) nd catt d urv ing lev ti n Al th gh thi ka t ycl i st ll ubje t to theo etic l deb te th c pt eem alid be u e d ffer nt t g s f land f m de l pm nt e ide t fiable t a s k r t f d ff g ge

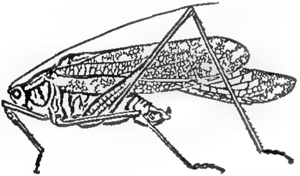
Not w thy k r t g a rel t ly u om m in sp te f te v l mest e te r i s th l ds f the e th The b st how ngs in E r pe e th K rst a f Yugo l i the Ca s e re g n f F d a G e e a d Andal s a N th Am r c n e mple ar f nd n thern Yu t n nt l Fl r da, the Appal ch n G e t Vall y T e s e d V g i i uth rn Ind d w t-ce t al Ke tucky J ma a P rto R c nd C b al o h e well-d l ped k t S CAVE GEOMORPHOLOGY GROU D W TER WEATH R C ROCESSES [J H B]

B bl g phy A H D err and D R Hoy K st l d p of Cub P rt R a d Ja m *Th Sci t fi M thly* O t. 19 7 v l 85 n 4 W D Th nb y *Pri ciple of G m ph l gy* 19 4 O D on E g In *G m phology* 1942

Katydid

Any of several bright green long winged grasshoppers of the family Tettigoniidae order Orthoptera The katydids occur throughout the Northern Hemisphere They are mainly herbivorous although there are a few carnivorous species Katydids are rarely of any economic importance although occasionally they may defoliate trees

The long antennae longer than the body are characteristic of the katydids and others of this family in contrast to the short antennae of the true locusts of the family Acrididae



The forked tailed bush katyd d *Scudde ia furcata* le gth to 2 in (F m E L Palme *Fieldbook f Nat al H story* McGraw H ll 1949)

In temperate climates katydids overwinter in the egg Eggs are usually deposited on twigs under bark or by splitting the edge of a leaf and placing the eggs in the slit *See* GRASSHOPPER ORTHOPTERA [J D B]

Kelvin bridge

A specialized version of the Wheatstone bridge network designed to eliminate or greatly reduce the effect of lead and contact resistance and thus permit accurate measurement of low resistance The circuit shown in the figure accomplishes this by effectively placing relatively high resistance ratio arms in series with the potential leads and contacts of the low resistance standards and the unknown resistance In this circuit R_A and R_B are the main ratio resistors R and R_b the auxiliary ratio R the unknown R the standard and R a heavy copper yoke of low resistance connected between the unknown and standard resistors

By applying a delta wye transformation to the network consisting of R R_b and R the equivalent Wheatstone bridge network shown in the illustration is obtained where

$$R = \frac{R\,R}{R + R + R_b}$$

$$R = \frac{R\,R_b}{R + R + R_b}$$

$$R = \frac{R\,R_b}{R + R + R_b}$$

By an analysis similar to that for the Wheatstone bridge it can be shown that for a balanced bridge

$$R = \frac{R_B}{R_A}R + R\left(\frac{R_b}{R + R_b + R}\right)\left(\frac{R_B}{R_A} - \frac{R_b}{R}\right) \quad (1)$$

If

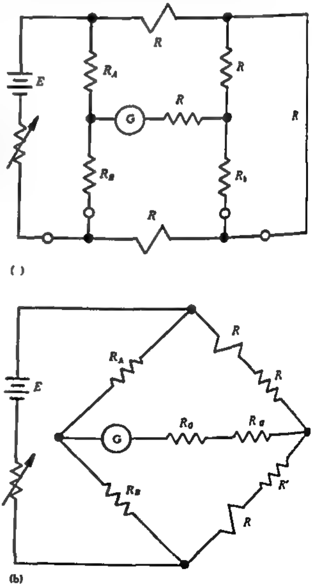
$$\frac{R_B}{R_A} = \frac{R_b}{R} \quad (2)$$

the second term of Eq (1) is zero the measurement is independent of R_y and

$$R = \frac{R_B}{R_A}R \quad (3)$$

As with the Wheatstone bridge the Kelvin bridge for routine engineering measurements is constructed using both adjustable ratio arms and adjustable standards However the ratio is usually continuously adjustable over a short span and the standard is adjustable in appropriate steps to cover the required range *See* WHEATSTONE BRIDGE.

Sensitivity The Kelvin bridge sensitivity can be calculated similarly to the Wheatstone bridge The



K l bridge ( ) Actual ci c it (b) Equi al t Wh at sto b dg ci c it

open-circu t, bal ce v ltage ppe ing the d tect termi als may be expre ed to a l se d gree f app tion as

$$e = E\frac{}{(\ +1)^2}\left[\frac{\Delta R}{R + R\left(\frac{}{r+1}\right)}\right] \quad (4)$$

The unb l nce d tect curr t for clo ed detect cir t m y be e pre d app ximat ly a

$$I_G = \frac{E\left(\frac{\Delta R}{R}\right)}{\frac{R_G}{(\ +1)} + R_A + R_B + R + R_s} \quad (5)$$

Th K l n b idge requ power pply pa of d t er g r l t ely large c ent d ing the tim a me me t i be ng m de The total lt g ppl ed t the bridge s u ally l m ted by the pow r d pat capab l ti s f the standard and k wn es st r

Errors K lvin br dg re st e-m u eme t er r rs a e ed by the me fact rs s f r the Whe tst bridge H w add t n l so rce of rror impl ed by the second t rm of Eq (1) m t b eval ted e th e fa t w ll eld m be red ced to e o F r m n m m e r the y k res t n h ld b m d a l w s po bl by phy lly pl c g the mm ly c ne ted c e t t rm l f th u kn wn d t nd rd a clo together a pos bl d c e t ng w th a l w re t ta e l d

The rat r t s h l de t lv th es t ce of th res t s b t l that of th i ter on ect g wi ing d ext n l leads nd th co t t r ta of th p te t l t t t ct Th term l l d re mo t l kely t ca e r and they hould th ef e b f th am r ist n e so that Eq (2) ll be f lfilled a n a ly as p s bl I add t n they h ld be el t ely hort n e the add t o f la g est ta c (lo g l da) will int od e o the l b ted t R_B/R F p m u ment t mm dju tme ts a qu ed the r ti arm r t nd p m d t e t th b dge re t int tw d ffe t Wh at t e b dg n figu ati s. By t ly b la g fi t th K l n n t k d th n h of th Wh t t t k thes dd t e r rt lly el m n ted S BR CE CIRCUIT RESISTAN E EASUREMENT [C A]

Kelvin s circulation theorem

A theo m fl d dyn m th t p rt s t a n mp es ble i c d fl d A d t n q f th theo m gr t mpl fi t n unde t d g d ly g a l g el of fl d fl w lled rr t t nal fl w (BE NOULLI S THEO- M LAPLACE S I ROTATIONAL MOTIO) The l t Γ bo t l ed rv m fl d d fi d th l e i t g l f the mpo e t f l ty l g th r

$$\Gamma = \oint \quad d$$

whe e v i the fluid eloc ty and ds is a length element l ng the urve (Ci culati n be rs a strong anal gy t the work done in mo ng a part cle around a cl sed curve in a f ce fi ld) Kel i s theor m states that in an inc mpressible in cid fl d the cir ulati n al ng a cl ed urve alw ys c nsi t ng f the same fluid particles does not hange with time An imp rtant co equence of thi the em relates to fluid motions starting f om rest or unif rm motion i such fl ws the cir ulat on is nitially ze o f r e ery po ble closed curve and h nc r mains q l t zer the eafter c rd ng to Kel in s theorem This impl es th t the l ne integral of the velocity taken from fi ed po nt A to fixed p i t B is indepe dent of the path from A to B Con ider for example tw differe t path C and C fr m A t B then $C - C$ forms a cl d ont ur a d the l ne in tegr l ro d it an shes showing th t the l ne int gr ls lo g C a d C re equal If the line i tegr l i dependent of path the integ a d mu t be a pe fe t diff e tial that s the velocity mu t equ l the grad e t f some sc la funct on $v = \nabla\phi$ so th t

$$\int_A^B \quad d = \int_A^B \nabla\phi \quad d = \phi \quad - \phi_A$$

whe e ϕ i called the el city potential a d is a f n ti f p it i the fluid nd time $\phi = \phi(r,t)$ Be u e

u l v = curl (gr d ϕ) = 0

the fluid mot on i i tat onal The fl id moti n is al o d erg c f e (ole o dal) f m sid a ti n of o t ity (s FLUID-FLOW PRINCIPLES) Thu t foll w that d v = d (grad ϕ) = 0 wh L pl ce equ ti [A E BR]

Kelvin s minimum energy theorem

A p i ipl of fluid mech ni wh ch state th t the t t n l m t o f an in ompre sible in d fl d occupyi g a mply on ect d g on h le k et c e rgy th n a y the fl d m t n o t t with the bo d ry d t on f ze o r l t e el ty n rm l t the bou da f th g n Th r m kable th o em is e sily p ed f ll ws Let T be the ki tic en gy f the i t t l m t n w th el city p t tal ϕ (s D ALE BERT S PARADOX LAPLACE S IRROTATIONAL MOTION) L t T th t c ergy f an the m t n with eloc ty fi ld $v = \nabla\phi +$ F om c nt u ty t f llow that $\nabla \quad = 0$ nd f m the bo nd y nd ti n $v_0 = 0$ on th b u dary wh r n t e t rmal t the bo ndary u fac It f ll w that

$$T = T + \frac{\rho}{2}\iiint \quad d \quad + \rho\iiint \quad \nabla\phi\, d$$

H e o $\nabla\phi = \nabla \quad \phi$ bec se $\phi \nabla \quad = 0$ and pply G d g n the rem t the last t gr l abo t be mes

$$\rho\iint\phi \quad n\, dA$$

which vanishes because $v_0 \cdot n = 0$ on the boundary. The second integral above is a positive quantity because its integrand is everywhere positive, thus proving that $T_1 > T$. *See* FLUID FLOW PRINCIPLES. [A.E.BR.]

Kentucky coffeetree

A large, strikingly distinct tree, *Gymnocladus dioica*, which usually grows to 80–90 ft but sometimes attains a height of 110 ft and a diameter of

Kentucky coffeetree, *Gymnocladus dioica*. (A. H. Graves, *Illustrated Guide to Trees and Shrubs*, Harper, 1956)

5 ft. The species name *dioica* means that the tree is dioecious, that is, male and female flowers are on different individuals. It grows from eastern Nebraska, Kansas, and Oklahoma to southern Ontario, western New York, and Pennsylvania, and southwestward to Louisiana. It can readily be recognized when in fruit by its leguminous pod containing hard, heavy, red-brown seeds which were used by early settlers as a substitute for coffee, hence the name coffeetree. The branches are stout and thick, and the bark has thin, twisted ridges. The leaves are twice pinnate, and the winter buds, sunken in the bark, are superposed, two or three together. Never a common tree, it is sometimes cultivated in parks and gardens of the eastern United States and northern and central Europe. It is sometimes used as a street tree. The wood is hard, reddish, and used for construction. It is durable in contact with the soil and is also used for railroad ties and fenceposts. *See* FOREST AND FORESTRY; TREE. [A.H.G.]

Keratitis

Any inflammation involving the cornea of the eye. It may involve the cornea alone (keratitis) or, more commonly, both cornea and conjunctiva (keratoconjunctivitis). The various forms of keratitis and keratoconjunctivitis together constitute a major portion of all eye diseases. Fortunately, many forms are not severe and do not result in visual impairment; nevertheless, keratitis is a disease of major importance, being second only to cataract and equal to glaucoma as a cause of blindness.

Corneal structure and injuries. The outer surface of the cornea is covered by a delicate membrane (epithelium) composed of flattened epithelial cells and closely resembling the mucous membrane lining the nasal passages and mouth. The substance (stroma) of the cornea is composed of interlacing layers of collagen fibrils similar to those seen in tendons, ligaments, and other connective tissues of the body but more regularly arranged. It is this regularity of structure that gives to the cornea its property of optical transparency. *Any alteration of this structural regularity* due to destruction of the epithelium or stroma or to the presence of pus, edema fluid, or scar formation results in an opaque region in the affected portion of the cornea.

Such an opacity will usually be temporary if the injury is limited to the epithelium but permanent if the stroma is also damaged. Although the response of the cornea to injury is similar in many respects to that of other body tissues, it is modified by the fact that the normal cornea does not contain blood vessels. Blood vessels from the surrounding conjunctiva are stimulated to grow into the cornea only if injury is severe enough to cause destruction and swelling of the corneal stroma. Since scar formation requires the presence of blood vessels, this means that injuries of only the epithelial membrane ordinarily heal without scarring. In such cases healing occurs by growth and spread of epithelial cells from adjacent uninjured zones over the injured area, leaving little or no residual opacity. These epithelial cells have a remarkable capacity for such growth and can completely recover the entire cornea within a few days. *Deeper injuries* which cause ingrowth of blood vessels leave a permanent mark in the form of a scar visible as a gray-white opaque region in the cornea. The degree of visual impairment is determined by the position as well as the size of the scar.

Etiology. Keratitis may be caused by mechanical injury, infectious agents (bacteria, viruses, fungi, protozoa), extremes of heat or cold, drying, radiation, corrosive or irritating chemicals, allergy, or may occur in association with diseases affecting the entire body, such as vitamin deficiency. Keratitis also frequently accompanies other diseases affecting the eye, such as glaucoma. *See* GLAUCOMA.

Since the cornea reacts to injury in only two basic ways, either by regrowth of epithelium in superficial injuries or by varying degrees of scar formation in more severe injuries, the degree of permanent impairment of vision is determined primarily by the extent of the injury rather than by the nature of the injurious agent. Of the various agents, bacteria are the most important, since a cornea injured by any means, and particularly a superficial epithelial injury, predisposes to bacterial infection, frequently resulting in damage far greater than the initial injury. *See* EYE; EYE DISORDERS. [W.K.AD.]

Keratoconjunctivitis (epidemic)

A al di e e ch r t z d by n acute conjunc u m follo ed by keratiti wh h m me ca es lea es r nd sup rficı l opacities m the c rnea f r up t 2 y r It ı al o kn wn as hipyard eye

The u l al ag nt deno ır typ 8 Diag ıs m de by olatı n f rus from ul r e-cr ti ns moc l ted int t s ue lt re r by th dem n t st n of nt body e ponses ı the blo d *S A* THODY

Spo di es nd ep d m c h e occurr d ın ma y c untries p rt c l rly ın h pya d and m d trıal pl ts Th mod f pread ıs n t po ı ti ely kno n R gid a ep ıs ın m dical di ıon I md t ıal m t tut s re ommended t p e ent po ble p ead by med cal att ndant r by n *trume t Se* ADE OVIRUS ANIMAL VIRUS

[J L M]

Kerogen

A ame g en to the c mpl x rgani matt r pr s-ent n c rbo ceo s h les and oil hal It ıs n sol bl ll c mm ol ent b t on de t uct d t ll t y elds o l g s a d cidic d ba comp nd Ker g s f m d by the b hem al and dy am hemi al *n of pla t and ani* mal rem ın both m y be pr e t n v riable pro-portı n It ı the m t comm fo m of o ga carbo earth and t h s be t m ted th t th e ı 1000 tım s m ch k ge a al Be a se f ts di r fi d or g ker ge ar es n mposıt n con t f pp ım tely 7–83% a bon 5–10% hyd gen 10–15% xyg and a mall p r t ge of t ogen *Se* OIL SHALE

[J A B]

Kerosine

Th r fi ed p t ole *m fra t* mpl yed a f l f lamps, jet eng n and m ll h t g appl a es, ch a c ok ng to f which g s l ne *t su tabl* K ıs d till d f om the fr e *t n ol n* rm l crud oıl bo l g betwe n 350 nd 5 0 F It r fin d to have p cific gr ıty of abo t 0 80 nd t *ma n l qu d t* about –25 F Th chem l makeup s p tty well l m ted t the n ble p r ffin s d aphthe (C to C) Th bec f t are r g d th rwı the mate-n l w'll not perf rm t fa to ly F t e th hydroc rbon m ke p m t be p affi c t avo d m ky fl m th c ty mu t b b ut po ses t ll w t fact ry f ed g by w k th n t of l t l mp t e wh h would l g the w ck m t be l w nd the lfur n t t m t b les tha 0 2% To edu e e plo-so h za d a fl h p nt f b ut 120–140 F pec fied.

K ros h s m sc ll neo e h fly s a sol ent f x ect c des It ı w del ed a f l f j t ng s and met m recip c t eng f l About 5% f the w ld de l p od t n, 2 5 000 000 b r l p r y oll s k *S* D TILL TE FU L PETROLEUM PROD-UCTS

[M S O]

Kerr effect

When a sub tan e ı pl ced ın an electric field ıt molecule may bec me p rtly oriented This make the s b tance anı ot op c and gı es ıt b f n genc th t ıs the ab l ty t refract l ght d fferentl ın tw d ection This ele trically ı duced birefrin gence di ered ın 1875 by J K rr ıs called the ele t oopti l Kerr effe t or simply th Kerr effect (F r di cu n of the m g etoopti l Kerr ff t see MAGNETOOPTICS) Th effect mu t be differen tiated from bir fringence d to mechanical t aın produced ı l ds by an electric field The Ke r ef fect cry tal s omet mes called the Pockels effect

When a l quid ı placed n an electric field ıt be-ha es optically l ke unia l ry tal w th the optic l axı parall l to the ele tric l es of forc The K effe t ıs u ally t erved by pa ı g light between two o den plat s ı rted ın gla s cell ntaı ng the liqu d S h a d ice ı known as a Ke r cell There are two p *ncip l ındic s* of efra t n *n* nd *n* (k own th rd n ry nd ex tr rdinary ınd ce) and the sub t nce ı alled a p sıt v ly o n gat ely birefringent ub ta de-pend ng n wh ther *n* — ıs po t e or neg tı

L ght pas ı g through the med um no m l t th lect line of force (th t ı pa llel t the co *den plates)* ı *split* nto two line rly p la ed wa es t vel w th the veloc ti *c/n* a d *c/* respe tı ely wh re c ıs the veloc ty of light a d with th elect ıc ector bratın p rpendicula nd p r llel t the l ne of force

The d ffe e n pr pag tion locity c u es a ph e d ffe en δ betwe the two wa s wh ch fo m no hr mat l ght of wa el gth λ_0 ıs $\delta = (-)x/\lambda_0$ wh re x ı the l *ngth f* the l ght path ın the m d um

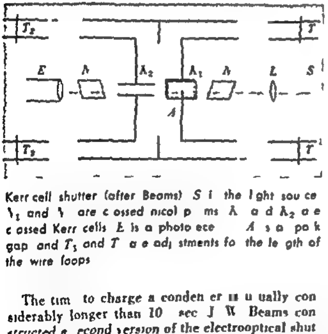
Kerr constant Ke fou d mp r cally that $(n - n) = \lambda_0 BE$ wher E ıs the elect field st ength nd B a c t t ch racteri ti of th ma te ıal lled th Kerr tant Ha el ck law st te th t $B\lambda n/(n - 1) = k$ wh n ı th re fr tı e ı de f the *ub tan e* the ab e f th fi ld a d k a c st nt ch r cte ıst f th *ub t n* b t depend t of th wa el ngth λ Ro ghly speak ng th Ke r co stant ı inve ly pr p t nal t the b l te temp atur Th ph s d ffe e e δ ı d t rm ned xper me t lly by *tand rd opt l tech* que If the w length λ ı e pre sed ın ntım te a d th field *t ength* E ın t t lt /cm (1 st t lt = 300 lt) the Kerr co tant f b d lfide wh ch h been *determ* ed n st ac u ately ıs B = 3 226 × 10- V *la of B* r ge f om –23 00 × 10- f r pa l dehyd t +346 0 × 10- f n t b n l

Th the ry f the Kerr *ffect* ı b ed n th fact that nd vidual mole ul a n t l ctr ally o-tr p but h e p rm t o ı d d el t c di pol The electr field r d t ı nt thes di pol s wh l th *n rmal th* rm l ag tatı t d to de troy the r t ı on Th b l nc that ı tr k dep nd on the z f th d pole m m nt th mag t d f th le tr f ld

This theory accounts well for the observed properties of the Kerr effect.

In crystals which are electrically polarized there may be changes in the refractive properties that are proportional to the first power of the electric field strength (Pockels effect). Such crystals also exhibit piezoelectric properties. The situation is made more complicated by the fact that in such crystals the index of refraction is represented by a tensor of the second rank and there may be in a general case 18 linear electrooptical constants. New crystals showing the Kerr effect have been used extensively for electrooptical shutters and birefringent filters. The Kerr effect here is independent of the piezoelectric deformation of the crystal, which also may produce changes in the optical behavior.

Electrooptical shutter. When a Kerr cell is placed between crossed nicol prisms so that the planes of polarization are 45° inclined to the axis of the condenser, no light will pass so long as the condenser is not charged. When an electric field is applied, there is a rotation of the plane of polarization and light is transmitted by the second prism. Since the orientation of the molecules in the liquid on which the effect depends is effected in times of the order of magnitude 10 sec, the shutter opens or closes in this interval. The time and duration of electrical pulses which control the shutter can be controlled by suitable electric circuits.

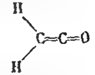


Kerr cell shutter (after Beams). S is the light source; N_1 and N are crossed nicol prisms; K_1 and K_2 are crossed Kerr cells; E is a photocell; A is a spark gap; and T_1 and T are adjustments for the length of the wire loops.

The time to charge a condenser is usually considerably longer than 10 sec. J. W. Beams constructed a second version of the electrooptical shutter which can open and close abruptly. It employs two identical Kerr cells K_1 and K_2 with the axes placed at right angle. The electric double refraction in K_1 is exactly compensated by that of K_2 as long as identical fields are applied to the two condensers. The condensers are discharged suddenly through a spark gap A, but wires of different length connecting the spark gap with the condensers cause the field breakdown to arrive at different times at K_1 and K_2. During this very short interval of imbalance light is transmitted. Kerr cell shutters have been used for the study of events requiring high time resolution. [C H D]

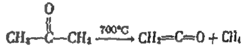
Ketene

A colorless, highly reactive gas, boiling point −56 C, melting point −151 C. It is soluble in ether and acetone and it decomposes in water and alcohol. The ketene molecule

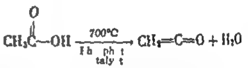


contains one of the most reactive carbonyl groups (> C=O) known.

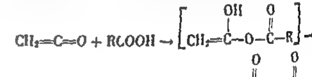
Ketene is produced by the pyrolysis of acetone vapor



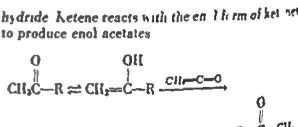
or of acetic acid vapor



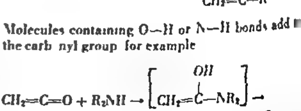
Carboxylic acids add to ketene to give acid anhydrides, and this is the basis of an important commercial process for the manufacture of acetic anhydride.



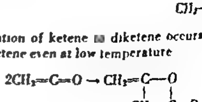
Ketene reacts with the enol form of ketones to produce enol acetates



Molecules containing O—H or N—H bonds add to the carbonyl group, for example



Dimerization of ketene to diketene occurs on storage of ketene even at low temperature



See KETONE. [D.A.S.]

Ketone

One of a cla s of chemical ompounds of gen ral f rmula RCOR wh e R and R are alkyl aryl or hetero yclic adicals The groups R and R may b the sam r d ff rent or in orporated int a g a in $CH\ CH\ CH\ CH\ C{=}O$ (cyclopentanone)

Th k t s acetone and methyl ethyl ketone are used a sol e ts Other ket nes re imp rtant a interm di tes in the synthe es of organ c com pou ds.

By comm n nomenclature rul s, the R and R groups ar n m d followed by the wo d keto e *f r e ample* $CH_3CH\ COCH_2CH_3$ (d ethyl keto e) $CH\ COCH(CH\ )_2$ (methyl is pr pyl ketone) $C_6H_5COC_6H_5$ (d ph nyl ket ne) IUC nom ncla tur the me of th hydroca bon c rre p d ing t th maximum n mbe of ca bon atoms i co ti u u chai in the ketone molecule f l l ed by on and pre ed d by a numb r desig u g th p t o f the carbonyl gr p in the c rbo h in. This gi e th names 3-pentan n and 3-methyl but non f r the first two ket nes abo e.

React ons of ketones Addition to th rbon l group i the m st imp rtant type of ketone e c t n Ket nes re gen lly le s eact tha alde h des n ddit on s tio s b t th methyl keton s (R o $R = CH$) a e apprec bly more e ct e than th r ket Th s eems due to the s z and st ri ffects l the atta hed gro

Hyd ogen dds *catalyt c lly* to th c rbo yl gro p d l th um alumi um hydr d gi es the same typ f prod t mely th seco dary l o h l The G ig rd e gent dd the ca b nyl

$$RCOR \xrightarrow[LiAlH]{H\ N\ \ \ Pt)} RCHOHR$$

p and tertiary alc hol e f med by hydr l y of th additi n p duct

$$RCOR \xrightarrow{R\ MgX} \underset{R}{\overset{OMgX}{RCR}} \xrightarrow[H]{H_2O} R{-}\underset{R}{\overset{OH}{C}}{-}R$$

The Refo m tsky reag nt $XZnCH\ COOR$ r act the Hyd g n yan de nd od um b sulfite will add to m thyl keton

$$CH\ COR \begin{cases} \xrightarrow{N\ H\ O_3} CH\ \underset{OH}{\overset{SO_3Na}{CR}} \\ \xrightarrow{HCN} CH_3\underset{OH}{\overset{CN}{CR}} \end{cases}$$

Al hol d not add eadily to the k t ne c rbonyl a they do to th ald hyd ca bonyl, b t ketals may be f rmed by th act n f rth f rmates

$$RCOR + HC(OC_2H_5)_3 \xrightarrow{H} R{-}C(OC_2H_5)_2R + HCOOC_2H_5$$

Amine deri at ves such as hydroxylamine (NH_2OH) phenylhydrazine ($C_6H_5NHNH_2$) and semicarbazide ($NH\ CONHNH_2$) add to the carbonyl by breaking N—H bond and with sub equent loss of water Th re ulti g oximes phenylhyd azone and semi

$$RCOR + C_6H_5NHNH \rightarrow \overset{NNHC_6H_5}{\overset{\|}{RCR}} + H_2O$$

carbazo es are u eful de ivati for the ident fica tio and chara ter zat on of ketone

Ketone supply alpha hyd og n in ald l type con den t n reacti ns but can supply a carbonyl *group o ly to l mited extent d e to* ts lower re activity

$$H_2CO + CH_3COR \rightarrow RCOCH\ CH_2OH \xrightarrow{H} RCOCH{=}CH_2 + H_2O$$

An xception i the elf-c ndensation of acetone to diacetone alcohol

$$2CH\ COCH_3 \xrightarrow{B\ (OH)} CH_3\underset{CH_3}{\overset{OH}{C}}CH_2COCH_3$$

The low r cycl c ketones generally h e more re act e carbonyl gr ups f r ll react ons due t the e posed p sition f th group nd to the rig d ty of the ng

Ket nes re xidized l s read ly nd less selec t ely than ldehyde to give ox d tion products h a c rbo ylic acids by cleavag f th b nds fr m the arbo yl ca b n at m to the adjace t tom They fail t g e the T llen and Fehli g s t sts although α hydroxy ketones will gi the t sts

Methyl ketones gi e the haloform *reaction with* lut o s f od e n aque us p t ssium hyd ox de

$$CH\ COR \xrightarrow[KOH]{I} CHI_3 + RCOOK$$

The oxyg n atom f the carbonyl *gro p of* ke to e may be r plac d by two hl rin atom by tr atme t with ph pho u penta hl id PCl_5 lth ugh in g ral the yield are poor

$$RCOR + PCl \rightarrow RCCl_2R + POCl_3$$

Chlo in o b omine will bstit t the alpha hy drog n at ms of keton s Th ulting α hal ke-

$$RCH\ COR + Cl_2 \rightarrow \overset{Cl}{R\overset{|}{C}HCOR} + HCl$$

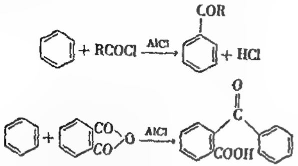
t n a q ite rea t e in d splacement reacti n f the h l g n atom.

Preparation of ketones Th d hydrog nati n or x dati f s condary al hol at el ted tem p rat r yi lds k t nd this i a alu ble com mer al method whe th secondary alc h l is f

$$RCH(OH)R \xrightarrow{Cu} RCOR + H$$

low cost as for example tho e obtained by olefin hydration

Aromatic ketones may be prepared by the Friedel Crafts reaction by acylation with acid halides or anhydrides



The Grignard reagent adds to nitriles to give ketimines which form ketones on hydrolysis

$$RC{\equiv}N \xrightarrow{R'MgX} R{-}\overset{R'}{\overset{|}{C}}{=}N{-}MgX \xrightarrow{H_2O} R{-}\overset{R'}{\overset{|}{C}}{=}NH$$

$$R{-}\overset{R'}{\overset{|}{C}}{=}NH + H_2O \rightarrow RCOR' + NH_3$$

Organozinc and organocadmium reagents give ketones upon reaction with acid halides The e organometallic compounds are best prepared from the Grignard reagent and the metal halide

$$RCOCl + R'CdX \rightarrow RCOR' + CdXCl$$

$$RMgCl + ZnCl_2 \rightarrow RZnCl + MgCl_2$$

Beta ketoesters formed in the Clai en condensation are cleaved by aqueous sodium hydroxide olution to form ketones

$$2RCH_2COOEt \xrightarrow{EtONa} RCH_2COCHRCOOEt + EtOH$$

$$RCH_2COCHRCOOEt + H_2O \xrightarrow{NaOH} RCH_2COCH_2R + CO_2 + EtOH$$

The Dieckmann condensation of esters of dibasic acids leads in imilar fa hion to cyclic ketones

$$EtOOC(CH_2)_4COOEt \xrightarrow{NaOEt} CH_2CH_2CH_2COCHCOOEt$$

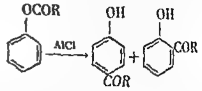
$$CH_2CH_2CH_2COCHCOOEt + H_2O \xrightarrow{NaOH} CH_2CH_2CH_2CH_2CO + CO_2 + EtOH$$

Both cyclic and open chain ketone are formed by pyroly is of calcium or thorium salt f dibasic acids or monoba ic acids

$$\tfrac{1}{2}CaOOC(CH_2)_4COO\tfrac{1}{2}Ca \xrightarrow{Heat} CH_2CH_2CH_2CH_2CO + CaCO_3$$

$$2RCOO\tfrac{1}{2}Ca \xrightarrow{Heat} RCOR + CaCO_3$$

E ters of phenols rearrange when heated with aluminum chl ride to f rm phenyl k t n (Fries rearrangement) in which the carbonyl group is ortho or para to a phenolic hydroxyl *See* ALDEHYDE CONDENSATION REACTION FRIEDEL CRAFTS REACTION GRIGNARD REACTION HALOFORM REACTION REFORMATSKY REACTION STERIC EFFECT (CHEMICAL REACTIONS) [D L S]



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Ketosis

An excessive accumulation of ketone bodies in the tissues blood and urine Ketone bodie are acetacetic acid β hydroxybutyric acid and acetone all of which are formed by the oxidation of fatty acid by the liver *See* KETONE

When a disturbance in carbohydrate metaboli m is present ketone bodies are produced in exces This results when the ti sue requirement for energy are not met by a readily available or utilizable supply of glucose Fat and protein mu t then be mobilized to the liver which transforms the e substances into gluco e a proce s called gluconeogenesis In the eries of bi chemical hifts involved fatty acids are oxidized in large am unt o that their normal breakdown product the k tone bodies accumulate *See* CARBOHYDRATE CARBOHYDRATE METABOLISM GLUCOSE

The ketone bodie by virtue of their acid pr perties hold an equivalent amount of ba e thus producing a f rm of acido i Thi i een clinically in certain cases of diab te in starvation occa i nally in hyperthyr idi m and in a variety of other di ea e state in which there is an ab lute or relative decrea e in carbohydrate availability *See* THYROID GLAND DI ORDER

In keto i the breath has a fruity odor and there is u ually eviden e of deh dration weakne s malai e headache nau ea and vomiting are common *Se* DISEASE PATHOLOGY [F C T]

Kidney

Pair d tructures fo ind in the d r al regi n f th b dy ca ity f animal bel nging t the rt br te il phylum Th e organ j rf rm a maj r part of the work f maintaining body fl u l at r per con entration and comp iti n C mparati e study of kidney tructure re eal vari u a lapt ti n re l ted t fly to th water pr blem in vari u h bit tat and gge t th j ien f en ir nm nt f ll we f in rtebrat e hi n

The nephron Th tru tural init fr m wh h all ki In y are f rmed i tl n phr n an ep th l al t l ul m r j i m i an l r wh t ariall m tru t ure In a typical ex mpl (Fig 1) Il d from the renal art ry p a th r ugh a l t t r of capillary l p the gl m r Bl l pr

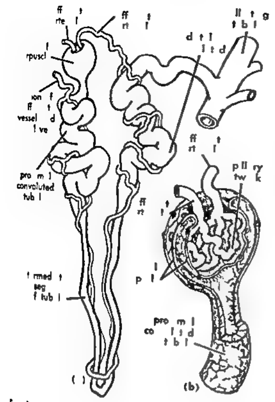


Fig 1 D g m t sh w t t f ph ( ) E t ph on (b) R l p l ly d ct d t sh gl l

f es a p rt of th bl d ell a d l rg m lec les e pted t filte th gh th perm ble gl m rul wall nd t t th e p ded e d of th tubul Cell n th w ll of thi tub le xt ct f m th p g filt at th b i n e t d s tuned f x t n d t rn them t th bl od adj ent p ll The e ell al xt ct cert n bst f m the blood d e c te th m int th tubul Th u e thu p od ced by e ch phron c n eyed by d t t th ts d u lly by way f bl dde

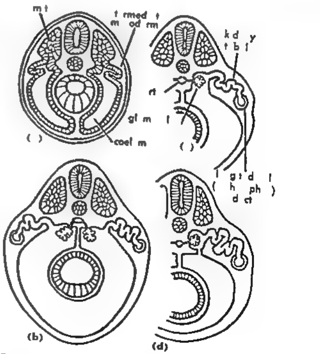
Evolutionary aspect It a um d th t the ect rs f ert b te we e m r f rm with body fl d at m t c qu l br um w th w t ll gr t t f e h wat r pos d th th t of r p d ll t n f b dy fl ds by o m Th phr b bly ev l ed d e wh h w ld u e bl d m t p mp t th u w ted w t r thr gh h gl m rul A l g gl m l p es nt mph b nd fi hes f d in f h w te t d y nd th eph b bly l ttl ha g d m th n est l typ H w whe fi h r ded th oc n ev l ed t l d f rms th oses n f gl m l bec m h b l ty b se f th w t r q i ed i pe at t Th bl m w m t by d ff nt ad pt ti ev l es f es l t A f w t l t fi hes h l t gl m l ti ly d p od e by t b t n al Th gl m rul h b e re ed n th m fi he nd s m m y lt-e t g ll in th g ll to f rth l

le te the w ter p oblem Sh rk retai the l rge gl mer lus b t ha e add d a pecial egm nt to the tub le wh ch retur urea to the blood i amount uffic ent t ra e the osm tic pre ure bo e th t of the cea Reptiles and birds ha e mall glom er li a d i ome ca es probably ave additio al wat by e c eti g nit og n s wa tes in the f m f a early d y p te f uric acid cry tals In the tubules of mammal and to a sl ght extent in bird a l ng thi walled intermediate s gm t has de el ped It i o effe ti e in water r o pti n that s me mammals i sp te of the r tent on f la ge glomer lu ar able t li e out their li es with ut acc t fre h water

Embryology Altho gh nephr ns are as embled to kid ey i a r ty f way the tubules l ways i i the intermed te mesoderm along the pp b rd r f th body ca ity (Fig 2) The fir t t bule dev lop at th a ter end f thi me o- derm f llowed by ther in seque ce behi d Va ia tio s th s pla p m t the follow ng k d ey type to b d tingui hed

H l ph s Th r is one ephr n beside each m te long the nt e le gth f th co l m Sup- po edly th s th ne tral c nditi o a d i thu efe r d to s n a ch neph n It ee today o ly in th l rv e f a few pr m ti e fi hes th myx d yel tomes

P o ph s Neph s are formed only i the ter or pa t of the termediate me ode m The p o eph s s r ly f u d a dult xcret ry g n b t s imp rta t beca s in ll mbry s it it ates th f rm ti n of the a chi phr c d ct sed by b q ent t bul s fo dr i age The p o-



Fg 2 D g mm t ct f mbry t h w g f ph ( ) E ly t g with m d m d f F t t (b-d) L t t g

til, in some in t ces th y a sume a stag horn shape. Cal uli are somet mes harmle s and silent b t m e often c se some d fficulty They may lead t infectio by erod ng thro gh the pr t ti e epi thel m d pr viding a f thold for ba teria o by c ing ob truction to urine flow When a st ne pa int the u eter the spa m of the ureteral m scl in ts eff rts to xpel the to e cau a o- lent pa kn n a enal c l c This i iten a com pa ed by bloody uri e as the t ne te s m ll blood es ls Most c lculi are pa s d o t of the bod ia the et Bl dd and ureth a Those h ch ar n t p ed may eq i e rgi l tre t ment lest th ob tructi and i fe t on pe man ntly dam ge the k d y

Infect ons Mo t i fect n f the kid ey are b c t n l a d el ted t the p l i Cla if tion c cord g to degr of er ty i as follow pyelit h n o ly the pel i lin s ol d pyel e- phr ti when the k d y ub is e i als aff cted and p eph o i wh the pel i greatly dil ted d filled ith p Th e fectio s e h ra ter t ca'ly a sociated with s me form of obstr cti n h h h s au d st of ine a d a fa orable m l e f r b ct rial gr wth Comm n u of ob- l ct n e e co ge st l ab mal t e of th ur t ra n women p o t t c g wth in eld rly men d lculi, t mors r l f prop r erv ont l of bl dde mpty g f ll wi g pi l co d d ea e n th Th rg m mo t f tro in l ed the l ba ll s and r lated gram negat e rod Th y p bably g i ece s t th k d ey by th bl od tream m e ften tha by a nd g th r t A t py l nephr t i a mp ed by h ll fev nd pu in th u ne Rec ry f m ingle attack i the rule w th h al g by rr g R peat d tta k chr i fe t ma destr y much k dn y t ss e th t ren l f l r u

T th l rms f fect on ar imp rt nt al th gh le comm Co t al b es m cu n f t t th t phylococcu pi c m s ngle mo oft n m ltuple l s If n h ab rupt es t th t de through the p i le of th k d ey pe n ph absces i f rmed Tube u k o g m mav nte th k d ey by the bl d lymph f m p mary s t i th lu g th infected o gan l unt e ted a the k d ey may be dest yed b the tube l us proc s and it may also be pr d i the bl dder nd th k d y

Glomerulonephritis Th m p l f rm f renal nfl mmat p rt c l ly ol g the glo- m rul Appare tly it result of a r n be- tween ulat g t ept coccal t n and t bod es p ese t th c ll f the glome l The b cter h b them el e do t t r the k d n ys, f nd h efly th thr at Th e a e two m n t f th d a Type I h abrupt et, ll l 2 weeks ft r n acut st ptococc l inf ct n Th u s m ky blood the blood p es u e h gh and n t g s t p od t r m kedly c a ed n the blood. M t pat nt rec e mpl t ly lth gh a few die in the early stages and a few others de velop hron c nephr t s Type II cases ha e an in s d ous n et with no ob i us preceding infection They manife t edema of the legs and eyelids ane mia protein uria and later hypertension Com plete reco y is r e and there is usually gradu l p gr ssion to omplete kidney failu e o er a pe riod of e e l ar In the early stage th k d n ys are e l rged l ter becoming increa ingly s arred and shrunken The glomer lar tuft are fir t enla ged and c llul with lat r carr ng and final di appearan e The rine c ntain red bl d cells and d ol ed protei which leak th gh the dam aged glome ul a well a precipitated pr te n n th form f ca t f the t ib le

Nephrosis (lipoid nephrosis) This is a disease of m ll childr n At the o et the e is a g adual c um lat on of t s e fl d noticed first as swell ing of the eyel ds and legs Th re is a marked lo s f protein in the uri e Th re ulta t ery l w level of serum album n is nadequate to perform th n r mal o mot c function of pull ng *wat r from the* t ue spa e nt the bl od tr am h nce the edema The blood ch le te ol i es to a very high level po sibly as th r s lt of the body s *mpt* to compen te f th l we ed pr tein le el The r n l l si n are btle c ns st n hiefly f well ng of th walls of the glome ular c p ll i s These sw llen w ll ar ex i ly p rou and th pro- te s l k th o gh them The ca e of thi ailment nk own alth ugh m st ca e e pr bably form f gl m r lo ephrit s nd elated t st epto- co cal tox s Some f th h ld en m k ompl *te* e r Othe d e f m b cter l i fections t whi h they are tremely sceptibl o fr m in t f r with b dy f n t n aus d by e c s i ac mulati of fl d Oth r develop hron c gl merul phr t w th hyperten n hemat r a and re al f l re

Nephrosclerosis Thi t rm f eq e tly appl ed t kid y d maged by rte i l s s or arter l cler U d th e o d t n s the rt r al v el *sthe large o m ll* bec m progre s ely n owe th p t o f r al ub t ce whi h they s t ply a e grad ally damaged by a x d e tu lly d *to be* epl ed by s t ue The k d ey lowly h ink and the t r u f ce be ome ough ed by depre ed a which lter n t w th th hyp t phi d st ll h althy terve i g t s u Ult mat ly m h p e hym may be de t oy d th t e l fa lu cc rs N phr l ro- s s only p rt of *g n r l* d d rd r f arte es alth gh th re al l em t m y b th d m a t f at e In th mal gn t f rm f n phros le ros s, th *arter le b com* c t c and rupt g g a fle bitten appe n to the k dney r f c l th form f th d a the ry h gh blood p e a d d th o *sea ly*

If d bet c mpl t n ph o l ro th r two d t nct *e feat e One* an ext me nar r w g f th t role the g n f the glo- m l The th r th p ese e of p cul r ound d p ll in th gl m rul Th i lled intr p l

nephros is of interest also because it shows features presumed to be primitive and suggesting a series of stages in evolution of the nephron as shown in Fig 2

Mesonephros The nephrons form behind the pronephros along the middle zone of the coelom The tubules usually become involved in sperm transport Drainage is through the archinephric duct The mesonephros never forms an entire adult kidney It is functional in the chick and other amniote embryos

Opisthonephros Nephrons develop from the middle and posterior portions of intermediate mesoderm The middle mesonephric tubules sometimes form only a minor part The archinephric duct may be supplemented or even replaced by ureterlike accessory drainage ducts This is the functional adult kidney in amphibians and fishes

Metanephros Nephrons form from only the extreme posterior part of the intermediate mesoderm and are drained by a distinctive new canal the ureter which grows forward from the base of the archinephric duct before the tubules have begun to develop This is the kidney of adult reptiles birds and mammals Their embryos show a distinct sequence of pro meso and metanephric kidneys (Fig 3)

Mature kidney The kidney as a whole tends to be long and straplike in fishes lying near the mid dorsal line and barely projecting into the coelom In other vertebrates it is considerably shortened and extends prominently into the posterior region of the body cavity sometimes suspended by a mesentery The number of tubules in one kidney varies from one to several million depending in part upon body size but also upon metabolic rate

In all classes of vertebrates renal arteries deliver blood to the glomeruli and tubules Except in cyclostomes and mammals blood also enters the kidney by way of a renal portal vein This carries blood from the tail and posterior parts of the body into sinuses surrounding the kidney tubules where it joins that brought by the renal artery and finally drains away through renal veins *See* URINARY SYSTEM [EBO]

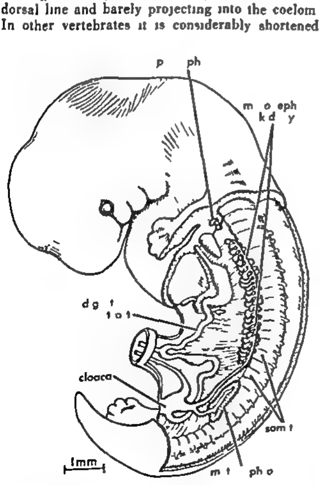


Fig 3 Human embryo of 6 weeks d sected to show the th ee success e k d eys wh ch d elop n th In termed te mesoderm

Kidney disorders

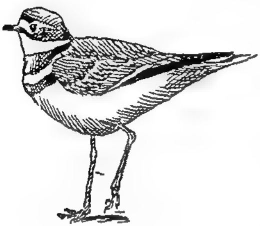
Probably because of their complex embryological derivation the genitourinary organs are frequently the site of developmental abnormalities Congenital absence of both kidneys permits only a brief postnatal life Absence of one kidney is common and produces no symptoms a single kidney being perfectly adequate for normal life Horseshoe kidney a descriptive term for fusion of the two kidneys at one pole is not rare Also familiar are double ureters double pelves and aberrant arteries These conditions are significant only if they produce obstruction to the flow of urine Obstruction due to any cause leads to dilatation of the proximal structures known as hydroureter if the ureter is involved or hydronephrosis if the kidney pelvis is affected One characteristic form of maldevelopment is the polycystic kidney in which both kidneys become greatly enlarged and converted into many thin walled cysts apparently because of a diffuse defect in development of the tubules Persons so afflicted usually develop renal failure and die in middle adult life

Calculi Stones in the kidney pelvis occur frequently There is a deposition of chemicals present in urine apparently starting in the tips of the papillae later protruding into the renal pelvis and ultimately breaking free There are several different chemical types of calculi occurring under different circumstances Uric acid and urate calculi reflect excessive metabolic production of these substances and appear particularly when the person suffers from gout Calcium oxalate calculi commonly occur if there are excessive oxalates in the diet derived particularly from fruits and vegetables Crystalline calcium carbonate and phosphate stones may occur when an overactive parathyroid gland increases the excretion of calcium when too much milk is ingested or when alkalosis decreases the solubility of calcium salts Amorphous carbonates and triple phosphates are characteristically found in calculi as a result of infection and stasis probably being deposited around a core of pus and bacteria Small calculi may be composed of a single component large calculi usually are of mixed composition

Stones may pass into the ureters when they are small or may remain in the pel and enlarge un

Killdeer

In f m r than 60 pecie f hor bi ds of the ' m! Char dr lae char cter ed by bill wh ch s sh rter than the head cont n ted at the middle i d l ghtlv s lle te m ally The n ck i me- h t h te tha that of the andp per There re ght sp c es n th Unit d States cl di g the killdeer *Ch d u cife* the be t kn w of all N rth Amer ca h re b rd The Ameri an g lden pl *Plu l d m i s* is not worthy f r it n so l m g atio r ut Ther are two dis



Th k ldee Ch d f l gth 10½ (F m E L P l F ldb ok f N t l H story M G w Hill 1949)

t nct r e F ll m r nt f the e t m r e le e th A ctc t d h m nd fi m ly th sea, d rectly f om w E gl nd t the pla n f South Am rica They ret rn n the p ng l r ly f h n d e t r ly l d by w y f Cent l Am i Mex d th Gr t Pl n S CH RADRIIF RM [J D B]

Killifish

A y f a la g fam ly of fi h th Cyp no- d t d u ally with fi fi pel d ales d f small to m d t e M t f th Amer n k ll fi h l a th su fa e of th wate ma y t th mar ll d t p m n w f th re son In rd w th th h bit the t p f the h d i flat tened nea the t th m th pens l g th uppe u fa e f the h ad a d th d r l fin t set fa b k Th k ll fi hes l y egg b t re the m l t th l ly l ted l be e u h th e ppy d *G mbus* S GUP Y

Th k llfish F d l p l gth t 4 l (F om E L P l F ldbook f N t l H st ry M G H ll 1949)

Many of the pe ie of this family e l il it harp exual dim pl sm tl e m les nd fem le l eing marked in di t ctly d fferent patterns Kill fi hes are widely d tr buted i No th a d South Americ Afr ca Sp i uth n A ia and tl e Fa t In l es In the United States they are most comm n i Fl r ida There re l tl fr h wate a d marine pe n the latte f eq enting hallow brack h water Fresh wat pe ie oc ur in the hoal areas f lakes a d i t am S CYPRINIFOR IFS SFXUAL DI IORPHISM [J D B]

Kiln

O e of e ral type of tructur f r heati g ce ram c (ea thy) m t ial in either their r w or m ld d fo m The heating p o n i all d firing wh h m y m n ither th oper ti n f th k ln r the tr tme t f the material in it bu n ng i a m e n lloqu l term appl d to the t eatme t of the prod t Wl en the he ti g s f unf rmed ma te ial t i ft alled calci ng

Ther d s t app r t be any le r cut d t f m e tl eryday u age r techn cal ter m nology b t e n th t m kiln f ce to e nd o e H we r a fairly widespread u ge n t e t ely co i te t r n t h c l te m K l seem t b ed ge erally n heati g f e amic mat r al t m th ng l th n mplete melt g f x mple eme t k l l me k ln b i k k ln and p tt ry k ln The term f ir a e i c mm ly ed wh n melt ng i i l ed i bla t furnace p he th f r ace nd gl s f r ac The l tt r may b alled a gla ta k wh the p c is e n t nu u but n a gla k l St e t u d t des- ig te a ga he t r su h s the hot t e ted w th bla t furn e In the c r mic du t i e are ge lly rel t ly low t mperatu e de- c s such a d y ng n the ther h d the coke n i r lat ly high temp ratu e de ce S FUR ACE CONSTRUCTION CLASS AND GLASS PRO UCTS

Shaft kiln Th type of kil s u d f r al in t g op at n u h s h tin l mest e t f rm l m qui kl m Raw mate ial i f d nt the t p and m e d w th ugh h t ga s flowi g up f m b r n e the s de at the l ttom the l d p duct em g s fr m the b tt m *S e* L TE (I DU T IAL)

Rotary kiln Th type f k l s cyli d up t 4 0 ft l ng l ed with r fr t ry i l d at a l ght gle d r tat d at a l w peed (b t re l t per m ut) A bu n (the f l is u ally p wde ed c al l) i pl ed at th l wer e d d th h t ga m e to th uppe end Raw m te al i fed nt the upp r end sl wly tumble d n th l ngth f th t be a d d p out th l e e d Us ally t f lls nt a o le in wh fi mb t p h t d Th m t mm n u f ot y k l i mak g p tl nd ment *S e* CE IENT

Th h fi nd t ry k l f tr t ng of rmed m t l p at e nt u ly Bat h ope ti f r w mat l e l c mm n but gyp m f

lary glomerulosclerosis and is associated with marked albuminuria

Kidneys in hypertension The kidneys are almost invariably diseased when high blood pressure is present but there is not a simple cause and effect relationship In the ordinary essential hypertension kidney tissue is often entirely normal after hypertension is well established strongly suggesting that the lesions of nephrosclerosis are the result rather than the cause of the elevated blood pressure Apparently the prolonged arteriolar spasm necessary to maintain the high blood pressure eventually leads to organic damage to arterioles followed by scarring of the kidneys On the other hand it is well established that damaged renal tissue may release pressor substances capable of causing hypertension Pressors may be produced in a kidney whose major arteries are markedly narrowed or in which pyelonephritis is present The hypertension so produced can be eliminated by removal of the diseased kidney

Lower nephron nephrosis This is the most widely used appellation for an extremely important acute reversible form of severe kidney shutdown It occurs following prolonged shock and hypotension or after absorption of certain hemoglobin compounds following incompatible blood transfusion or after destructive injuries of muscle The sequence of events following the original injury is suppression of urinary secretion usually complete followed by rising blood levels of nitrogenous wastes After about 10 days urine secretion usually commences again but the urine first produced consists chiefly of water with relatively little nitrogen In due time which may be as long as 2 months the renal function returns to normal Death is not common unless the original injury is itself fatal or the patient receives too much fluid which he cannot excrete Because of its reversibility this particular renal lesion is one of the best suited for treatment by the artificial kidney

The renal lesions are relatively subtle and inconstant consisting of edema of the tissues between the tubules heme casts in the tubules and focal injury to tubular epithelium chiefly of the distal nephron

Renal failure When the kidneys are unable to carry on their normal functions of excreting waste and balancing the internal chemical environment of the body renal failure is present This may occur abruptly as in lower nephron nephrosis or obstruction of the urinary tract but most often develops gradually because of progressive destruction of renal tissue by disease The sequence of events is about the same whether parenchymal destruction is the result of pyelonephritis glomerulonephritis nephrosclerosis or other cause

In the early or compensated stage the kidneys lose their functional reserve that is the ability to meet stress The power to excrete concentrated urine when little fluid is taken in or to excrete a dilute urine when much fluid is ingested gradually disappear and the urine specific gravity ultimately becomes fixed at 1 010 the specific gravity of an ultrafiltrate of blood serum Similarly nitrogenous wastes cannot be selectively concentrated but are merely washed through Also ability to excrete bases or acids to compensate for shifts in intake and to maintain the normal pH (7 4) of blood gradually vanishes

In the later or decompensated stage complete excretion of certain substances is no longer possible and their blood concentrations rise Most important of these substances are potassium phosphates and nitrogenous wastes such as urea and creatinine Sodium and water accumulate in the tissues in edema fluid Edema is also aggravated by fall in serum albumin caused both by loss in the urine and poor intake in the diet In children with chronic renal failure the phosphate retention produces severe disturbances of calcium metabolism which sometimes results in a bone disorder called renal rickets Anemia is usually present for several reasons of which probably the most important is destruction of red blood cells by circulating poisons

The end stage of renal failure is uremia Symptoms include convulsions vomiting diarrhea and coma Lesions are found in many organs They include fatty droplet accumulations in heart muscle acute fibrinous pericarditis ulcers of the intestinal tract a white powdery frost on the skin and edema of the brain These changes are reversible if the renal failure can be relieved Extensive studies have failed to pinpoint the particular poison or poisons responsible for the individual lesion

Cysts Single or multiple cysts with thin walls containing clear fluid are extremely common They often result from obstruction of tubules by scars and are not important except in polycystic kidney

Tumors There are three important malignant tumors of the kidney all having a high mortality rate Wilms tumor found in infants is made up of a mixture of small glands and of sarcoma cells particularly of muscle type it is often termed an adenosarcoma The tumor usually occurs as a large abdominal mass and is rapidly fatal if untreated Some children are cured by radiation and surgery Renal cell carcinoma or hypernephroma grows in the renal substance of adults as a hemorrhagic yellow usually encapsulated tumor The first symptoms may be irregular fever hematuria or those of distant metastasis Because it invades the veins early it tends to metastasize through the bloodstream particularly to lung brain and bone Metastases may appear many years after the kidney tumor has been removed Sometimes there may be solitary metastases curable by surgery Transitional cell carcinoma arises in the epithelium of the pelvis produces hematuria early and tends to spread down the epithelium of the ureter *See* KIDNEY METABOLIC DISORDERS ONCOLOGY URINARY SYSTEM [R N B]

Bibliography A C Allen *The Kidney Medical and Surgical Diseases* 1951

pro ectu n f fi e ware (a in decorat ng d nner ware) s needed the high co t of lectr c heating m be justified It is u ed widely in labo atory f aces bec e t p rmits el e temperature control S e CERAMIC TECHNOLOGY PYROMETRIC CONE TEMPERATURE CONTROL, AUTOMATIC [M C M]

Kilogram

A nit of m s The ta dard of mas n both the mk and cgs y tems of units s a platinum rid ium cylind alled the t ndard k logram The un t of ma t the mks syst m is the ma s f the dard kilogram The u it of ma in the cgs system hono f th s ma s and is called a gram A kil gram weighs 2.20462 lb a d a metr c ton con t n 1000 kil grams

The kil gram s al o omet mes defined as un t of f rce that i the weight of a 1 kilogram m ss hence the xpre o kilogram f rc Se MASS UNITS SYSTEMS OF [L N]

Kinematics

That b an h of m ha ic whi h deals with the mo n of a sy tem f mat l particle witho t refe en e to th for e wh ch a t n the sy tem K ne m t c d ffer f m dyn m cs in that the l tter takes these f e nto cc nt *See* DYNAMICS

Fo a l p rticle mo ing n a str ight line (recul e r m ti) the motion i p esc ib d when the pos ti f the part le s k own a fu c ti n f the t me F r un f rmly acc le ated m ti n,

$$\frac{d^2x}{dt^2} = a$$

h e t th c ta t eler t on and he ce

$$x = \tfrac{1}{2}at^2 + v_0t + x_0$$

h x_0 d s e the n t al po tion and el city of the part l p t v ly *Se* ACCELERATION M TION RECTILI E R VELOCITY

Pl k em t of part l is c n er d with th pecifi t of the po ti of a pa t le m ing pl by m a s f two d pende t ari ables n ally th ect ng l r atte an c rdi ates x a d y b t lten th p lar coo d nat $r =$ (+ y) θ = t (y/) other co r d ates that m y be espec lly en ent for p rt la p blem Her the x a d y mp ent f loc ty e d /dt dy/dt nd f e lerat on d² /dt d²y/dt espect ly but th e mp ent of loc ty the d ect n of n e t and i er g θ r d /dt a d (dθ/dt) and are th not so mpl gi t ms of th t me d t ati es (th oo d n te

The k nem t s l p t le i sp on med w th th w t wh h thr depend t on d s es may be ch en to fy th p ti n f th p rt l t t m d w th th el tion bet ee th fi t d se o d tim der ti f these oord tes d the mpo t of loc ity a d a l t n of the p rt le Th m t n i pecified f th ee th oordinates are g n a functions of the time and the path of the particl in pace s then obtained by eliminating the time b tween thes eq iation

For de cr bing the simultaneous position in space of N particles $3N$ o dinate re necessary and the configu ation of the system may be repre s nted by a point n a $3N$ dimensional pace called th *configuration* pace of the system As the parti cles mo e the corr pond ng representati point in configu on pace traces out a curve called the trajectory of the ystem If the particles do not move independ ntly but a ubject to m con straints that i if m rel ti ns between the $3N$ coord nat s cont nue to hold throughout th m tion then it is possible to represent the trajectory in a space of $f = (3N - m)$ dime s ns f being the n mber of degre s of fr edom of the ystem See CONSTRAINT DEGREE OF FREEDO (MECHANICS) For a igid body en though N and m a ery large $f = 6$ and the c nfigu on at any time may b represented by i ndependent variables (usu ally three t r pr sent the pos ti n of the c nt r of ma and th angles to pecify the ientati n of the body ee CAYLEY KLEIN PARAMETERS EULER ANGLES) Ki emat s de cribes the rel tion be tween the t me der tives of such angl s and the omponent f the ng lar eloc ty of the b dy

Amo g the coo dinate sy tems t died in kine matic a e those u d by ob ervers who are in rel t e m tion In nonrelat i t c kinemat cs the time o d ate fo e ch such bserver is ass med to be the me wh r s in relati tic kinemati s pr pe a co nt must be tak n of the fact that length and time nterv l app ar d ffe nt t ob rv rs mo ng relati e to ach other S e RELATIVE MOTION [H C C]

Kinescope

A cathod ay tube used as tele s on picture tub It m ght al o b refe ed t a a telev i n p t e rep odu r Modern televis n p cture t bes u u lly ha e l gla e v l pes (se F g 1) on the nner fa e of wh ch a l ght m tti g layer f l m n e nt mat i ls i d p t d A modu lat d t m of high l ity electr s is made to c th s layer n a s r f ho iz ntal lines s that t ecreate the p tu element (light nd dark a a)

The numb r of le tr ns in th t e m at any in t t of t me is va ed by ele t i l mp l es o pond ng to th gn l ent o t by the televi o tr n m tter Th le tr cal imp l s (p t ure nfor m t) ent ut by the transm tter w origin lly g nerated by a tud televisi am ra The l m televi m e t p cks p th s gn l nd aft r u tabl ampl fi at o nd detect on the pi t r nf rmat n s uppl ed to th picture t b so that it will r cre t the g nal pi tu Se TELEVISION

Construction Th mo t p p l pictur tubes rrently in u e re the 17 l a d 23 i t gu l z Th d m n i n ref t th d agon l of th e ta g l r fa e Fo d t iled d

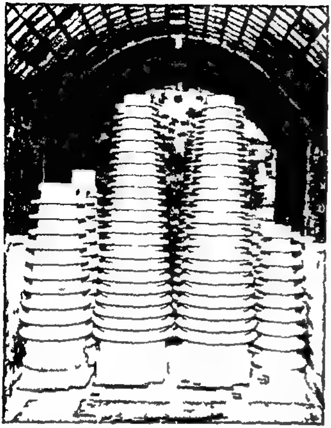


Fig. 1. Interior view of a periodic kiln showing a setting of electrical porcelain insulators ready for firing. (Swindell-Dressler Inc.)

example, is heated at relatively low temperatures in kettles to form plaster of paris. *See* PLASTER OF PARIS. Kilns for firing formed ceramic products may be either periodic or continuous in operation.

Periodic kilns. In this type of kiln the cycle of setting ware in the kiln, heating up, soaking or holding at peak temperature for some time, cooling, and removing or drawing the ware is repeated for each batch. Such kilns range in size from laboratory or art pottery kilns with chambers a few inches on a side to large domed structures 40–50 ft in diameter used to fire brick and other heavy clay ware. Large combustion-fired kilns are known as up- or downdraft kilns, depending on how the hot gases move through the kiln from firebox to exhaust. Periodic kilns have relatively low efficiency because the heat used to raise the kiln itself to temperature is largely thrown away each time the kiln is cooled, although some of the heat may be used to operate a drier.

Chamber kilns. This type of kiln represents the first step toward continuous firing, and it consists of a series of adjacent chambers in a ring or oval. Firing is arranged (with a movable stack) so that the fire moves from chamber to chamber around the ring, taking several days to make a complete circuit. The flues are so arranged that waste gas from the fire passes through chambers toward which the fire is moving and heats them, while the combustion air is lead to the fire through chambers already fired and is preheated. The preheating of both ware and combustion air (by waste gases and cooling ware, respectively) gives a considerable increase in efficiency over the period kiln. Although widely used in Europe, this type of kiln was never adopted in this country.

Tunnel kilns. These are long structures with the fire located near the midpoint. The kiln is designed so the temperature rises gradually from each end to a maximum in the middle. Ware is fired by loading it on cars which are pushed through the kiln, thereby subjecting the ware to a heating, soaking, and cooling cycle. Since the kiln itself remains at essentially the same temperature and only the ware and kiln cars are heated and cooled during each cycle, operating efficiency is higher, both in terms of fuel savings and of less wear and tear on the kiln. Tunnel kilns range in size from a few feet long (with a cross section a few inches on a side) to over 100 ft long (and a cross section up to 6×8 ft).

Muffle kiln. In this type of kiln a refractory wall or chamber prevents direct contact between the flame and the ware. It may be periodic or continuous in operation, and it is used in firing products such as high-grade dinnerware when the price of the ware justifies the expense of a less efficient firing operation.

Kiln furniture. These are refractory shapes used for setting and supporting ware in the kiln. They include pins on which glazed ware is set and the posts and plates from which shelves are built on a kiln car.

Saggers, a type of kiln furniture, are refractory chambers or boxes in which fine ware is set for firing. They differ from muffles, which are a structural part of the kiln, in that they are set in the kiln at each firing. Besides protecting ware, they provide support for pieces which become soft at the firing temperature.

Heating. Heat for kilns may be obtained from the combustion of wood (largely obsolete), coal (becoming less common), oil, or gas, or from electric heating elements. Oil and gas are preferred for large manufacturing operations because they combine economy with fair ease of temperature control. When close temperature control of a high-priced product (for example, electroceramics) or when

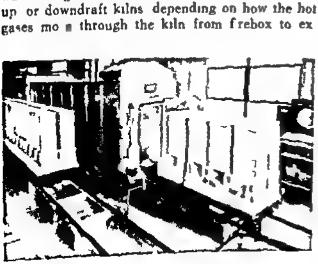
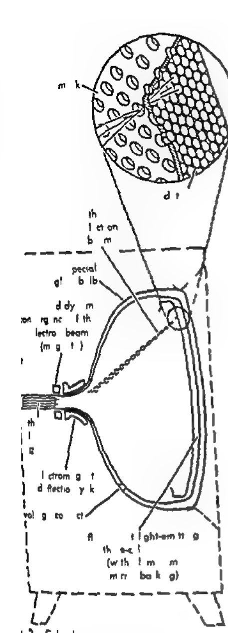


Fig. 2. View of a medium-sized tunnel kiln used to fire fired ceramic floor tile. (Swindell-Dressler Inc.)



l 2 C l k p

Color kinescope A c l r t l i p tu tub m'l t th bl k d white p tur t ibe but ff in t way (1) Th light m tt ng e m d p f m ll elem t l e h p ble l m tt g l ght n f the three p m v l (ed g bl) l d t nt l ed r y (2) M a p d d f le t ly t g an m f th ph ph p m e C l m y be t ll d b a y f th ee method (1) s g h h t urat lect n beam bing f des ed ph ph r a w th feedl k g l f m th n th gh r tr wh h m r r t l t g f th l m( ) ( ) a t h g d d g t red w th th n b h d fl t th l am t the pr per th th (3) a se ee t ut e wh h p de f mph x t d g t m d t l eam d ection g lly ed w th th e gul rly sp ced be ms The third devic i termed a shadow mask tube

All c lor pictur t be are omewhat limit d in l ght tput as mpar d w th l l ck and white t bes by the f ct that th ph pho s are h en for ex ell nce of primary col r rathe than high lumi us efficie y S me c lor systems have add ti nal output lim tatio f the e re n col r tubes are usually operated at higher c rrents a d v ltage than their l lack and white unte part Altho gh each colo tub vstem has certa n ad a tage only the shad w ma k type ha be n c f lly devel ped for high produ tio Its ad va tages are it abil ty t pr duce c lor as pure a ph sph r p im te ex ellent co t a t th fea bility of u g it a fine barely percepti bl d t s een t ct re and the fa t that the cur re t fr m three beam a d l e f r imultaneous p e e tat n A cu re tly a ailable c mme cial h d w ma k tube con t of a 21 n-diameter r nd gl b lb 70 m x mum d flecti n angle a triple b am gun having elect ost ti l cu nd m gn tic me n fo keep ng the three ele tr n b m c nve ged to a p nt and a urved ap rtu e m k reg ter d with and l e to the pho phor d t ee The d t in he gonal r y dep ted on the sph r cal faceplate M gn tic sca ning a d yn h nized dynam c on ergenc are u ed (see Fig 2) S e COLOR TELEVISION [C I S]

B bl g aphy L. S All rd D ign f ctor n t le th d ray tub s *P oc IEE (Lo do)* 99(3a) 499-507 1952 D C F nk (ed) *T le s n E g n t g H ndbo k* 1957 H B Law A th e gun shadow ma k ol r k e cop *P oc IRE* 39(10) 1186–1194 1951 H R S ele et al D el pment of a 21 m tal e vel pe c l r ki e sc pe *RCA R v* 16(1) 122 139 1955 C P Sm th t l De gn nd d l pment of th RCA 21CYP22 21 i ch gl l n tur t be *RCA Rev* 19 334-348 1958

Kinesthetic sensation

Th k d f feel ng gin ti g i bod ly mo ment d ar g fr m tim lat n of th n o y erve that t m n t n mu le te d n d j nt It i by m f k ne th (l t lly f l ng f mo- t) th t t l e m p ble t w lk w th it look i g t the f et eat with ut w t h g th hand con ey food t th m th r t mate th w ght of ob- j t me ely l y heft ng th m

F r well o e t ry e the t me f S Ch les B ll (u d 18 6) the m l e a t we th lled h been rec gni ed a s xth t b dd d t th cla l f e of Ar t tl g he ng feel m ll a d t t At fir t ry et n l m m les w tl ght t l lu ly esp ble f pply g f mat n abo t po t al h g H w e th ev de g ad ally c me to fa tl nerve d g t ted d ti l (jo t) t p d g th b lk f ch d t Now t i kn wn th t app ta t of limb m m nt he f the maj rity f post r l dj tm t n y d by w y f re ep-

cathode ray tube construction *see* CATHODE RAY TUBE This article discusses construction specific to kinescopes

Deflection angle This is the maximum angle through which the electron beam must be deflected to scan the picture area Most tubes in use today have deflection angles of 90 or 110

Focus Picture tubes are defined by the method used to focus the stream of electrons to a small spot There are two general methods magnetic focus using a strong external electromagnet and electrostatic focus accomplished by applying voltage differences to the electron gun electrodes Electrostatic focus has become universal because of its lower cost

Electromagnetic deflection The electron beam is deflected electromagnetically to cause it to scan the picture area This deflection is accomplished by a deflecting yoke made up of two pairs of shaped coils which fit around the small neck of the picture tube (see Fig 1) When pulsating electric currents of proper wave shape and phase are supplied to these coils they generate magnetic fields which cause the electron beam to bend as it passes through them By changing the magnitude and direction of the magnetic field the electron beam can be made to arrive at any point on the face of the picture tube

Glass envelope The glass envelope is made of a special composition to minimize optical defects and to provide electrical insulation for high voltage It also provides protection against x radiation and has a light absorption characteristic which improves the contrast of the picture when it is viewed in brightly illuminated locations The structural design of the glass bulb is made to withstand

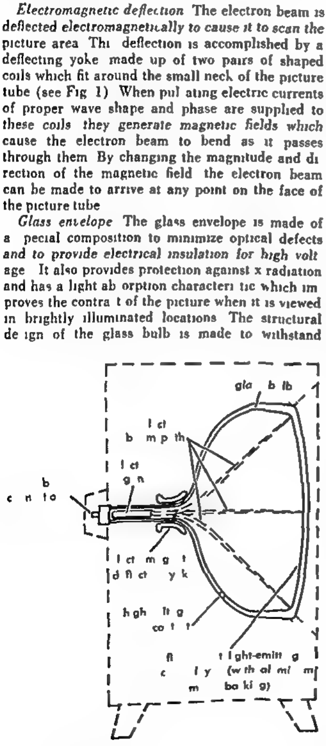


Fig 1 Black-and-white kinescope

3–6 times the force of atmospheric pressure to provide a safety margin over normal atmospheric pressure However care must be taken in handling these evacuated glass bulbs or a dangerous implosion may result

Aluminized screen The luminescent screen is made of a thin layer of phosphors 0 001 in thick (3 mg/cm²) The phosphor materials are primarily zinc cadmium sulfide (emits yellow light) and zinc sulfide (emits blue light) By careful proportioning and mixing of these two phosphors the resultant emanation is a blue white light which most manufacturers have adjusted to a color temperature of between 9000 and 12 000 K

The luminescent screen is aluminized by vacuum evaporation from a small molten aluminum pellet The thin layer of aluminum approximately 2000 Å is deposited on a smooth plastic film placed on top of the luminescent screen The plastic film is subsequently volatilized and removed in the high temperature processing of the tube In the operation of the completed tube the high velocity electron beam penetrates the aluminum film and its energy is transferred primarily to the luminescent screen Only a small percentage (10–20%) of the electron beam energy is converted into useful light energy but even this amount is sufficient to produce brightness of several hundred foot lamberts in the picture highlights The reflection of light by the aluminum mirror increases the picture brightness and improves picture contrast by preventing stray light from illuminating the back side of the luminescent screen

Wall coating Graphite coatings are placed on the inside walls of the bulb to provide electrically conducting surfaces between the screen and the electron gun and to provide a unipotential field through which the electron beam may travel without being disturbed by stray electrostatic fields Graphite is a sufficiently poor conductor to minimize eddy current power absorption from the electromagnetic fields generated by the external deflecting yoke

Electron gun The electron gun produces a stream of high velocity electrons which are focused to a small spot at the screen In currently used commercial tubes the spot produced by the electron beam at the screen is approximately 0 025 0 125 in in diameter depending on beam current required (usually 50–1000 microamperes) The beam current is controlled by an electrical signal supplied to the cathode with respect to grid No 1 called cathode drive or to grid No 1 with respect to the cathode called grid drive Conventional tubes require 50 125 volts of signal to modulate the beam from zero beam current (picture dark areas) to maximum beam current (picture highlights)

Transistorized portable battery operated TV receivers use picture tubes requiring less signal voltage much less power for deflection of the electron beam and smaller amounts of power to heat the cathode from which the electrons are emitted

d tributi n f nction The main purpo e of ki etic theory is to deduc f om the t ti t cal d cr p- t n r lts al d fo th wh le sy tem The d s tinct bet een kinet c theory nd stati tical mechan cs is th f nec ty arbitrary and ague H t rically k eti the ry s the olde t stat sti al d scipl n Today a k n tic c lculat on refers t any calculat n i wh ch p obabil ty methods mod els, r d trib t on funct n s are n olved

F r inf rmat n hi h is relat d to and upple m ts the pre ent rt cle *see* STATISTICAL MECHAN ICS *s e al* o BOLTZMA N STATISTICS BOLTZ MA N TRA SPORT EQUATION QUANTU I STATISTICS

Classes of problems Kinet calc l t on ar n t rest ted t ga es but o c r n chem cal p ob- l m sol d stat *problems* and *pr blems in r* d a t n theory E en tho gh th g neral pr edure i th se d ff rent areas are im la there a e a uffi c nt n mber f impo ta t d ff renc s to make a gen l la ficat u ef l

Classical d al equ l bri m p obl ms In the e there a e o t t a t on between the n titu nt of th tem Th sy tem is qu l b m and the mech ical l erning th sy tem re cla al The b inf m t on is co ta ned n the B ltzma n d tribut *f* (al call d Ma well r M x ll B ltzm nn d tr buti) wh h g e the n b of parti le i g e momentum and po ti l ge ($d\,x = d\,d$)d d $= d\iota\, d\, d$ wh e x, y and a e oo d nate f po t o a d t t a d e coo di tes of l city)

$$f(xy \quad) = A\,e^{-} \qquad (1)$$

H i th ene gy nd $\beta = 1/kT$ (wh e k i th B ltzma n t t nd T s th absol te tem per tu) and A a o ta t dete m ed f m (2)

$$\iint d^{3}\, d^{3}\, f = N \qquad \text{total n mbe f pa t cles} \qquad (2)$$

Th e lcul i f gas pre e p ifi heat nd th l cal equ p rt ti n theorem e all ba ed n th se l t n

Cl al id l qu l bri m p bl m Ma y mporta t phy al p ope t e refe t t q l b m b i t n q il l um tates Ph me a h th m l c d t ty ty and elec t ic l cond t ty ll r qu e a d c on tart g f m th B ltzm n t po t q atio

$$\frac{\partial f}{\partial t} + \quad \nabla f + X\,\nabla f = \left(\frac{\partial f}{\partial t}\right)_{coll} \qquad (3)$$

h X = f r e pe n t m = ha g n f d t ll If o e d al w th t te that e q l b m th x ct Boltzm eq at ed n t be sol d b it t nt t de be th n t r ry t at as mall pert b t n pe imposed a eq l brium t te E th gh th r g u d u n f th o q lib m p oc esse d ffi lt app al t mple phy al p ct f eq ntl l d t qu t t t bl express n term f th qu l b m d t ib t f ti Of one l import the mpl of th o-called electron gas in a m tal The k netic treatme t f th s sy tem f rms the basis f r th cla cal (Lorentz) conduct ity theory For tates far from equlibr um n g neral simple theory exi ts

Classical n n deal eqi ilibr um theory The ba c cla ical procedu e for arbit ary systems (sy tems with i teraction taken i t account) that allows the calculation of macroscop c entitie i that using the pa tit on functio

$$Z_I = e^{-A/kT}$$
$$= \frac{1}{N! \lambda} \int \quad \int d^3 x_1 \qquad d^3 x_N\, e^{-(1/kT)U(x_1} \quad) \qquad (3a)$$

where $\lambda = h/\sqrt{2\pi mkT}$ Here A is the thermody nam c fre ene gy and h is Pl nck s con tant Al th ugh Eq (3) is written th t it may b applied to ga es th part ti n funct on may al be written for cl s al sp n y t ms s ch as ferrom gn ti lid parama netic ol d nd the l ke Th math emati al problems f e luat ng the ntegral or the um are d ffi lt. Equat n (3*a*) with appro- p iat m d ficati n is the st rt g poi t f r all these n id rat ns

Clas cal nonid l o equ l b ium the y Th is the mo t g ne al tu t on that cla al *statis- t c* e n d cribe In g ner l ve y little is k wn bo t h syst ms Th Li u ille equ t on ap- pl s and ha be n u ed s a tarti g point for thes tud b t n p cta lar r sults ha e yet be n obtained F r tudie f th liqu d tate how er the results h e b n q te pr m sing

Q t m p obl m The e ar quantum c nter p t to the clas ificati n ju t d scribed I a qu ntum t atm t a d tr b t o fu t n s al u d f an ideal y tem n equ l br um to desc ibe t g n al pr pertie F yst ms of part cles hi h mu t b d cr bed by symmetri l wa e f tion s h as hel um at ms a d phot ns one h s

$$f(\quad \iota \quad) = \frac{1}{(1/A)e^{\beta} - 1} \qquad (4)$$

wh e th Bo e d str but $\beta = 1/kT$ nd A is de t rmin d by Eq ( ) *S* BOSE EINSTEIN STATISTICS F y tem of pa t cl wh h mu t b de crib d by a t symm tric l w f n t s *h* as el c tr pr to s a d n ut n h

$$f(\quad \iota\,) = \frac{1}{(1/A)e^{\beta} + 1} \qquad (5)$$

I f the f n t n n l l ti n s ctu lly n t y d ff nt f m th e of th clas cal d t but o f ct o b t the res lt ar quite d f fe ent, a the a alst l d ta ls As n th l s I a th tre tm t f th neq lib um st te can b ed e d to a tr tment n ol g the eq l br um d t b t n nly The appli at to le trons as (ideal) F m D ra ga in met l th ba of th Somm rf ld theory f metal (s e FREE ELECTRON THEORY OF METALS)

tors at or near bony articulations The most crucial evidence comes from abnormalities Joint sensibil ity may be retained in the presence of muscular and cutaneous anesthesia of the same region The con verse also occurs such as retention of sensibility of skin and muscle but failure to discriminate passive movement of the limb because articular sensitivity has been impaired

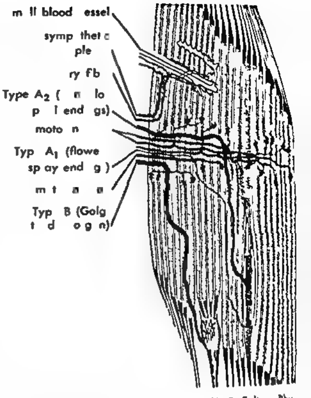
Kinesthetic receptors Four types of ensory nerve ending are involved in the appreciation of bodily movement They are (1) free nerve endings (2) Pacinian corpuscles (3) Golgi tendon organs and (4) muscle spindles

Free endings These are the most commonly oc curring sensory nerve terminations in the body They are found in deep tissues—subcutaneous lay ers fascia (musclesheath) periosteum (bonecover ing)—as well as at the cutaneous level where their distribution is almost ubiquitous and where endings of neighboring nerve fibers overlap and interdigi tate with one another in some profusion The pre sumption is that it is the free endings of the perios teum and the fascia that contribute so heavily to kinesthetic sensation though this is by no means firmly established Free nerve endings are also sus pect as initiators of pain which can be most ex quisite in the periosteal and fascial regions

Pacinian corpuscles Pacinian corpuscles are the largest of the specialized sensory nerve endings in the body being situated suitably to serve as kin esthetic receptors They are found in the sheaths covering muscles and tendons and are scattered through deep fatty tissue Relatively few in number they are encapsulated consisting of many concen tric layers of fibrous tissue containing nerve end ings are attached to large diameter sensory fibers and are known to respond to any nearby distorting force whether it be muscular contraction or me chanical deformation transmitted from the body surface

Golgi tendon organs These organs situated near the junction of muscle fibers and tendon would seem to be most advantageously placed to report on muscle movement Recordings of electrical changes in th ir attached fibers show them to signal both muscle stretch and active contraction Impulse fre quency has been found to be roughly proportional to the common logarithm of the tension impo ed on the tendon Golgi organs may therefore be thought of as muscle tension recorders

Muscle spindles The most complexly organized of the kinesthetic receptors are the muscle spindles which have two distinctly different kinds of termi nations These ha e been de ignated Type A_1 (flowerspray endings) and Type A_2 (annulo piral endings) by the British phy iologist B H C Mat thews who originally described them Typically A_1 fibers are of smaller diameter and are therefore slower conducting than A_2 fil ers Both types initi ate impulses when their mu cle bundle is tretched and generally cease firing impulses when the mu cle contracts The fibers leading from mu cle spindle therefore have been termed stretch afferents Type



Nerve e d gs in muscle sensat on (J F Fulto Phy ology of the Nervo s System 2d ed Oxf rd 1943)

A_2 additionally generates kinesthetic impul es when its muscle is very strongly contracted

Kinesthetic discriminations Since it is the re ceptors situated in the neighborhood of bony artic ulations that supply the most exact information about bodily movement the finest kine thetic di criminations are as ociated with joint di place ments Measurement of the ability to di criminate such movements is accomplished by arranging for a limb or appendage to be moved mechanically and passively at a uniform rate and the least detectable amount of movement based solely on feel is deter mined In such experiments it is typically found that the greatest sensitivity is associated with the larger joints (hip and shoulder) while the lea t is found in the ankle and toes At a speed of di place ment of 10 /min thresholds vary roughly between 0 2 (hip) and 0 7 (main joint of big toe)

Since appreciation of postural change seems to depend mainly on articular sensitivity the roles of muscles and tendons must be secondary in kine the sis Muscular and tendinous sensitivities pre um ably add feelings of strain when resistance to limb mo ement is encountered as in lifting weight or pushing against stationary objects *See* SOMESTHE SIS

[F A G]

Kinetic theory of matter

A theory which states that the particles of matter in all states of aggregation are in vigorous motion In computation involving kinetic theory the meth ods of statistical mechanics are applied to specific phy ical system The atomistic or molecular struc ture of the system invol ed is a sumed and the system i then de cribed in terms of appropria e

Equip t t n th rem and sp c fic he t In a cl l id l ga the erag ki t ene gy s soci ted w th y tr latio al deg e of f eed m the same

$$\tfrac{1}{2} \overline{\iota} = \tfrac{1}{2}\overline{m} = \tfrac{1}{2}\overline{m^{\,2}} = \frac{1}{2\beta} = \tfrac{1}{2}kT \quad (15)$$

It q t t a htf rw rd to h w that the ge energy a soc ted w th ny degr e f f dom h h occur as a qu drat c t rm the expres fo the me han c l e rgy i gi en by ½ kT For m ll the ult p es s th t f Boltzmann d trib t wr tte in term of m menta and g er lized oord t d q h

$$\overline{q\frac{\partial}{\partial q}} = \overline{p\frac{\partial\epsilon}{\partial p}} = kT \quad (16)$$

h h s lled th q partit theorem F m th eq p rt t theo em th p fi he t C defi ed by

$$C = \frac{\partial \bar{E}}{\partial T} \quad (17)$$

m y be mmed t ly bt ned

If h j t th three t an l t al d g f f eed m the a ge ergy p degree f f d m m lec l ½ kT h nc th a ge gy $\bar{E}$ = $\tfrac{3}{2}NkT$ a d $C = \tfrac{3}{2}R$ Th p ific heat s th t t d dep de t f T In th of d t mi m l l n s lly h three t l t l d t t o l d gr s of f e d m The f $\bar{E} = \tfrac{5}{2}NkT$ a d $C = \tfrac{5}{2}Nk = \tfrac{5}{2}R$ ppose th re a toms l d e ch b d b el t f e t nt l th t ca th m h l ergy w ll be

$$\frac{1}{2m}(p + p + p^2) + \frac{1}{2}k\ (x^2 + y^2 + z^2) \quad (18)$$

h e k i the el t c fo ce t t Ac d t th eq p t t th o m th t rm ll g e a p c fi h t $C = 3Nk$ the D l g d Pet t l f m t m c l d (S ECIFIC HE T OF OL DS) Th q p rt t th r m pe ll ful whe g i t a t mper t h gh th r t b m ne e y t e elat t mech t d cr b th y t m p p ly Th h ppe at t mpe t f wh h th th rm l en gy kT f th m d m The p- r pri t r l i bet e n gy d m m t m then

$$= C[(p + p + p^2) + m c^2] \quad (19)$$

(REL TIVI TIC M CHAN CS) Th q p rt t latio (16) m th be tte

$$\overline{c^2p^{\,2}} = kT \quad (19\ )$$

F m th r l t t t ect t th a gy f g th lt th l

$$\bar{E} = \tfrac{3}{2}NkT\left(1 + \frac{5}{4}\frac{kT}{m} + \quad\right) \quad (19b)$$

El ctric l c d t tity of m t l Exper mentally o e b erve p p rtionality between the appl d electric field a d the current p oduced in a met ll c co d t r Kinetic procedures g e an expl t of th general nnect on C de th l tr s in a metal as an ideal gas of electro of m m charge e In equilib ium the electrons a e de cribed by the B ltzmann d tr bution (1) or the F m Di c d t ib t on (5) C ll this distri b t f Be a f depe d n t + t + t o ly t clear that $\bar{\iota} = 0$ n et cu rent can fl w n eq l b m t te The applicati n f n ele tric field th r f re lt in the destruct on f th ph cal symmetry i the l t es Thi ffe t is d rib d by the Boltzmann tran p t equati n

$$\frac{\partial f}{\partial t} + \quad \nabla f + \quad \nabla f = \left(\frac{\partial f}{\partial t}\right)_{coll} \quad (20)$$

The llision te m cau es c derable d ffic lty In m y p blem o e j tified i trod cing r l t n time whi h may d pend n x d t d wh h defined by

$$\left(\frac{\partial f}{\partial t}\right)_{coll} = -\frac{f - f_0}{} \quad (21)$$

H f s the d tr b t f n t at therm l equ l b m The intr d tio f su h relaxat t me p e upp e th t a quil b m tate w ll decay e p ti lly t quil b um tate as on e q of the a t n f the ll io Th s u d btedly a g od pp imat r equil bri m A me th exi t e of n l tr fi ld n the d t n wh h d to t th n t l d t ibution a m ll m t By i g Eq (21) Eq (20) may be wr tten

$$\frac{eE}{m}\frac{\partial f}{\partial} + \quad \frac{\partial f}{\partial x} = -\frac{f - f_0}{} \quad (22)$$

H E s the t l elect c field If it s n w a um d that $(f - f\ )/f << 1$ with f very n r q l b m t t s th t q d t c te m m y b l cted a d th t the pa mete A d β n f dep de t f x the e plicit e p ss n f f be bta ed

$$f = f \quad - \quad E\iota \frac{\partial f_0}{\partial} \quad (23)$$

Th el tri r t n th x d e ti n i lw ys g e by

$$J = \int e\iota\, f d^3 \quad = -\ e^2 E \int \quad \frac{\partial f}{\partial \epsilon} d^3 \quad (24)$$

(Th fi t te m Eq (23) d not o tribut t th t h s l eady bee p t d t) Th n e mpl f a f rmal res lt in t p rt th ry The res lt f r J i n a form n wh ch ly k owl dg f the eq l b m d t b t r q d t bt e pl t we

In quantum theory nonideal systems in equilib rium are described in terms of the quantum parti tion function

$$Z_g = \sum g_i e^{-E_i/kT} = e^{-\psi/kT} \qquad (6)$$

Here E indicates the energy levels of the system and g indicates the weights of the e levels If one defines a Slater sum by

$$S(x_1 \quad x_N) = \sum e^{-E_n/kT}|U_n(x_1 \quad x_N)|^2 \qquad (7)$$

where $U_n(x_1 \quad x_N)$ is the wave function of the state n Z_g may be written as an integral similar to Z

$$Z_g = \int \quad \int d^3x_1 \quad d^3x_N\, S(x_1 \quad x_N) \qquad (8)$$

For the applications the energy levels and the wave functions must be known In the evaluation of S given by Eq (7) the symmetry character of the wave functions must be explicitly introduced It is sometimes easier to use the grand partition func tion

$$Z_{gr} = \sum_N \sum e^{(\mu N - E_N)/kT} \qquad (9)$$

Here μ is the chemical potential and E_N is the nth level of a system having N particles The cur rent theories of quantum statistics as for example the hard sphere Bose gas are for the mo t part concern d with questions in this area

The only technique now available is that of the density matrix It is possible to express certain en tities which characterize transport properties uch as the conductivity tensor in terms of the unper turbed stationary den ity matrix A complete di cussion of the validity of the approximations is till lacking In addition once the cond ictivity ten r is obtained in terms of the density matrix of the stationary (but *still interacting*) system a prob lem of the same order of difficulty as the evalua tion of the quantum mechanical partition function remain if explicit expre i ns for the e quanti ties in term of the forces between atoms are de sired

Classical examples Kinetic theory ga e the first insight into many of the phenomena that take place in ga es as well as in metal where the free (conduction) electrons can be con idered as an ideal gas of electr n The following example il lustrate some of the more fundamental calcula tions that have been made

Ideal gas pressur A cla ical ideal ga is de cribed by the Boltzmann di tribution f Eq (1) (*see* GAS) The con tant A is given by

$$A = \frac{\Lambda}{V}\left(\frac{m\beta}{2\pi}\right)^{3/2} \qquad (10)$$

where m is the ma s of an indi idual m lecule and V is the total volume of the gas A ga exerts a force on the wall by virtue of the fact that the molecules are reflected by it The component of momentum normal to the wall changes its sign as a consequence of this collision Hence if the normal velocity of the molecule is v the momentum given off to the wall is $2mv$ To calculate the total force on a wall one needs the total momentum transferred to the wall per unit time Let dS be a small section of the wall, and call θ the angle made by the molecule s velocity vector with the normal to dS (ee Fig 1) From Eq (1) the number of molecules that have a peed $c = (v_x^2 + v_y^2 + v_z^2)^{1/2}$ and whose velocity vector makes an angle θ with a given axis (call these $c\ \theta$ molecules) is

$$f(c\,\theta) = 2\pi\, Ae^{-1/2\beta m c^2} c^2 \sin\theta\, d\theta dc \qquad (11)$$

The number of such molecules that in time dt will collide with dS (assuming spatial homogeneity) i given by

$$dS\ c \cos\theta\ dt\ f(c\,\theta) \qquad (11a)$$

From this information an interesting ide re ult may be calculated namely that the number of all collisions with a unit area of the wall per econd is

$$2\pi A \int_0^{\pi/2} d\theta \sin\theta \cos\theta \int_0^\infty dc\, c^3 e^{-1/2\beta m c^2} \quad (1\ )$$

If one introduces the average peed $\bar{c}$ as

$$\bar{c} = \frac{1}{N}\iint d^3x\, d^3c\; cf \qquad (12a)$$

the total number of collisions may be written a $\frac{1}{4} n\bar{c}$ Here $n = N/V$ the number density This re lation is of importance in calculating the efflux of gases through orifices Each $(c\,\theta)$ molecule con tributes a momentum of $2mc \cos\theta$ to the wall per collision Since the pre sure p is given by the force per unit area or the total momentum tran ferred per unit time per unit area one obtains f r p

$$p = \int_0^\infty \int_0^{\pi/2} 2mc\cos\theta \quad 2\pi Ac \cos\theta\, e^{-1/2\beta m c^2} c^2 \sin\theta\, d\theta\, dc \qquad (13)$$

$$p = \tfrac{1}{3}\Lambda m\overline{c^2} = (\Lambda/V)\beta^{-1} \qquad (14)$$

Since it is known experimentally that $pV = NkT$ where k i the Boltzmann constant $\beta = 1/kT$ i now identified This pre sure calculation is a typi cal example of a kinetic theory calculati n

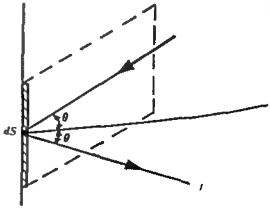


Fig 1 Ch g of mome tum of g s m lec le o st kes a wall; i I it al loc ty; f al loc ty

Th m a that a rela ation time describ th de ca from a tate so near a equil bri m tate th t h the molecul s ha tra elled (on the a er age) o e m a free path the equ lib um is re establ hed Stated differe tly the no equ l b um st te i n the a rag o e c llision per m lecule rem ed f m th eq lib um tate

Exp sion (28) may ow be e aluated in terms f the mean f ee p th as

$$Fo = \text{per unit area} = \tfrac{1}{3} nm\lambda c \frac{dv}{dy}$$

From th s, th vi ty coefficient follow d ectly

$$\eta = \tfrac{1}{3} nm\bar{c}\lambda \qquad (33)$$

I trod cing the mean free p th as gi en by Eq (30) one ees th t

$$\eta = \frac{1}{3} \frac{mc}{4\pi \;\; ^2} \qquad (33b)$$

Th emarkabl r lt is th t the isco ty is in deed *independ t f the p re S ce*

$$= \sqrt{8kT/\pi m}$$

the o ty d p d o th t mper t e but not n th p es e Th s m wh t unintu t result s on of the fir t t iumph f k netic th ory Both pects f Eq (33) re in g d agreement th e perim t f ot too low de t s η is in deed ndepend nt of the p essur η also p o- port o l t the squ e root of the t mperature

[M DR]

B bl g phy R H Fowler *Statist cal Mech n* ic d ed 1936 D Ter Haar *El m ts of Sta tistical M ch* 1954 C. K ttel *Eleme t ry Statist c l Physic* 1958 *s e also* STATISTICAL MECHANICS

Kinetics (chemical)

Th bra h f phy cal hem try con rned w th the mech n ms nd ate of chem l ct n The st dy of act at on gies of r a t o also an imp rt nt t p c n chem l ki etic.

Reaction rate The rate at wh ch chem cal re act t re ed up or at wh ch ch m c l p oduct f rmed is import nt t pic partı la ly ı o g n h m try nd b chem t y wh m ny d ffere t p od ts c n b obt ned all f which a po l acco d g t th rmodynam al l t on The p od t tu lly obt ed i determ ed by the l t rates f the comp t g rea t n The e f e, kno ledg f t n r tes i mp rta t in contr ll g ch m l re ts

Rat t nt The p fi te c ta t *k* is u e f l in l l t e ct n r t at v o s e tr t ins. If i a mple hem cal e t o A → B the t of rea t n i d ectly p oport al t the ncent t n f A th prop rt nal ty t *k* is lled th pec fi r a t n r te t t Thu

$$\frac{-d}{dt} = kc_A \qquad (1)$$

where $-dc_A/dt$ is the rate of decrease in concen tration f A with time *t* The rate of ch nge will dec ease as A is used up and its concentratio de creases but the rate will always be pr po t onal to the concentration Thus if *k* has a alue of 0 01 per minute 1% of A which is p ese t at any tim t will react pe minute O er long periods of time the concent ation will be cha ging dur ng the time interval and it is nec sary to teg ate the equa tion Thus

$$k = \frac{2\,303}{t_2 - t_1} \log \frac{c_A}{c_A} \qquad (2)$$

whe e c_A the c ncentration t time t_1 and c_A is the c ncentrat on t t me t_2 Thus it is possible to d term n th r te co stant *k* f m the measu ements of the c ncentrat on of A at tw d ffe ent times When the ate co tant has been evaluated by ex perim ntal measurements or by theoret cal calcul t ons s poss ble to calc late accu ately the con centrat n c_A at any later t m when it i known at one tim Frequently the known concentrat on c_A i taken as the initial c ncentration start ng at zero time

Orde f r action The o d r of react n d pends on the e ponent of the concentration whi h deter mines th at of the reaction Thus in Eq (1) the eact n s first d I an th type f reaction wh ch d p nds on the collisi n of two m l cules A + A → A th rate g en by the fo mula

$$\frac{-dc_A}{dt} = kc_A^2 \qquad (3)$$

S ch a ct n lled a sec nd order eact n If the e ction is A + B → AB the r te of the re action m y be g n by the relat n

$$\frac{-d_A}{dt} = \frac{-dc_B}{dt} = \frac{d\;\;_B}{dt} = kc_Ac_B \qquad (4)$$

The rea t on at s first o der with r pect to A and first de with r pect t B but the o r all re actio r t s id t be seco d o de Th r actio order i q l *to th* sum f the po nt of the conce t ti s of ll the r ti mat rial I fi st ord r ction *k* is m ly ratio nd is i depend t of the u ts of ce trat on u d In a ec d-o d e ct wh ch d pe ds n the p od ct of the *ce t t on* the co st nt *k* i ludes te m f r the *con ntrat on* Its num i l e d p d on th co ntrat n unt u d s ch as moles p liter

Wh th time terv l i l g it is ecess ry t tegrat d formula Th s Eq (3) b come

$$k = \frac{1}{t} \frac{x}{(\;\;-\;\;)} \qquad (5)$$

nd Eq (4) b omes

$$k = \frac{2\,303}{t(\;\;-b)} l \;\; \frac{b(\;\;-x)}{a(b-\;\;)} \qquad (6)$$

In the case of Boltzmann statistics use of Eqs (1) (2) (10) and (24) gives

$$j = \frac{Ne^2\tau}{m} E \tag{25a}$$

The conductivity $\sigma = Ne^2\tau/m$ cannot be compared with experiment unless the relaxation time τ is known. In the Fermi case the evaluation of Eq (24) is facilitated by observing that $\partial f_0/\partial\epsilon$ has a δ function character. Call $A = e^{\beta\mu}$ so that Eq (5) reads

$$f_0 = \frac{1}{e^{\beta(\epsilon-\mu)} + 1} \tag{25b}$$

It is easy to show from (25b) that

$$\frac{\partial}{\partial\epsilon}\frac{1}{e^{\beta(\epsilon-\mu)} + 1} \cong -\delta(\epsilon - \mu) \tag{26}$$

for sufficiently low temperatures. This allows the immediate calculation of Eq (24) also for the case in which the relaxation time depends on the velocity.

Viscosity and mean free path. One of the early successes of kinetic theory was the explanation of the viscosity of a gas. Strictly speaking this is again a transport property and as such it should be obtained from the Boltzmann transport equation (20). It is possible however to give an elementary discussion. Consider a gas that is contained between two walls or plates, the lower one ($y = 0$) at rest and the upper one constrained to move with a given velocity in the x direction (see Fig 2). A force is necessary to maintain the constant velocity of the plate. This force is given by

$$X = \eta A \frac{dv}{dy} \tag{27}$$

Here dv/dy is the velocity gradient and X is the viscous force (also sometimes called the shear stress) on the area A which is perpendicular to the diagram. (X is the component of X in the x direction.) Equation (27) defines η the viscosity

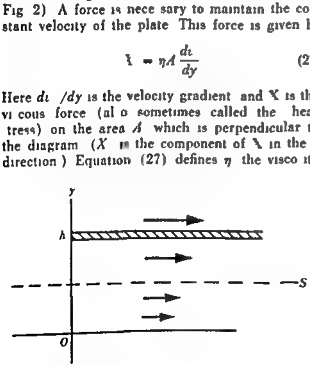


Fig 2 Explanation of viscosity. The plate at $y = h$ is moving with velocity v and the plate at $y = 0$ is stationary. The horizontal component of velocity of the gas molecules goes from 0 at $y = 0$ to v at $y = h$. Momentum must therefore be transferred across S by the vertical component of velocity.

coefficient. The physical reason for this force stems from the fact that molecules above the surface S have a greater flow velocity than those below the surface. (This will certainly be true on the average.) Thus molecules crossing from above to below will carry a larger amount of momentum in the positive x direction than those crossing from below S upwards. Hence the net effect is a transport of momentum in the x direction across the surface. By Newton's second law this will yield a force. The computation can be carried out in this manner. Consider an area in the x plane. The number of molecules passing through per second is $f v_y A$ where f is the distribution function. The amount of momentum transported in the x direction is (per collision) $f v_y A\, m v_x$.

The force per unit area is the sum of these terms

$$\sum f v_y v_x m \tag{28}$$

For the evaluation of this sum the notion of mean free path is useful. The mean free path is the average distance traveled by a molecule between collisions and is usually designated by λ. To investigate this entity imagine each molecule to be a hard sphere with radius a. If a molecule moves with average speed $\bar{c}$ it sweeps out a volume $4\pi a^2 \bar{c} t$ in time t. If there are $n = N/V$ molecules per unit volume the number of collisions per second is given by the collision frequency z

$$z = n4\pi a^2 \bar{c} \tag{29}$$

For a typical gas (oxygen) under standard conditions $n = 3 \times 10$, $\bar{c} = 4.5 \times 10$ cm/sec and $a \cong 1.8 \times 10$ cm. Hence numerically $z = 5.5 \times 10^9$ collisions/sec. The average distance between collisions, that is the mean free path, is

$$\lambda = \frac{\bar{c}t}{n(4\pi a^2)\bar{c}t} = \frac{1}{n(4\pi a^2)} \tag{30}$$

Numerically $\lambda \cong 8 \times 10$ cm. This discussion is of course exceedingly crude. Making the calculation on the basis of a Boltzmann distribution gives

$$\lambda = \frac{1}{\sqrt{2}\, n(4\pi a^2)} \tag{30a}$$

Using similar methods it may be shown that the distribution of the mean free paths (that is the number of molecules whose mean free path lies between x and $x + dx$) is

$$dN = \frac{N_0}{\lambda} e^{-x/\lambda}\, dx \tag{31}$$

There is an interesting connection between the mean free path and the relaxation time introduced previously. It should be stressed however that this connection follows more from a qualitative discussion than from a rigorous calculation. One would guess that

$$\tau = \lambda/c \tag{32}$$

Thi mean that a relaxat on time de cribes the de- c y from a st te so near an equilibrium state that hen the m lec les ha e *tra elled* { *n* the er age} e me free path the equilibrium r re-establ hed Stated d fferently the nonequilibrium state s o the a erage one coll sion per molecule rem ed fr m the equ libr um state

Expres on (8) may ow be evaluated in terms of the mean free path as

$$\text{Force per u t are} = \tfrac{1}{3}nm\lambda c\frac{dt}{dy}$$

From this, the visco ty e efficient foll ws directly

$$\eta = \tfrac{1}{3}nm\bar{c}\lambda \qquad (33a)$$

Intod cing the me n free path a given by Eq (30) one ee th t

$$\eta = \frac{1}{3}\frac{mc}{4\ a^2} \qquad (33b)$$

The r m kable result is that the vi cos ty is in deed independe t of the p e re Si ce

$$c = \sqrt{8kT/\pi m}$$

the visc s ty depends on the tempe ature but not *on th* pres u e Th s s m what unintu t e r It s o of the fir t t mph of kinet c th ory Both a pect f Eq (33) a e i good agr ement with p r m t fo t too l w d ities η t in deed i dep ndent of the pr ur η is al o proportion l t th squa e oot of the temperature

[W DR]

B bl g phy R H F wler *Statist cal Mech n i s* d ed 1936 D T r Ha r *Elem nts of Sta tis ca M hanics* 1954 C K tt l *Eleme tary Statisti l Phy s* 1958 s e *al* STATISTICAL MECHANICS

Kinetics (chemical)

Th b an h f phys cal hemistry n rned w th the mech n ms nd at of chem al react ns Th tudy of acti at n e e gi s of reaction i al o an imp t t pie hemic l k netic

Reaction rate Th rate at wh h h m l re- tant are u ed p or at wh h hem cal p od cts e formed an imp rt nt top c p ticularly i o g c chem try nd b hem try wh r m ny diff ent prod ct can b bta ed all f wh h a e po bl ac d g t therm dyn m c calculations Th prod t ct lly bt ned det rm n d by the el ti e rates f th comp ting ctions Th e- f e, a k *owledge f* ctio at s mportant in t oll ch m cal *ct o*

R t nst nt Th pec fi rat n tant k i u e ful in c lcul t ng ct n tes at a i u tr u s. If s *imple* hem cal ct $A \rightarrow B$ th rate f r t is d re tly p po t o l t the e t u f A the pr port n l ty c t nt k is lled th pec fi re cti rate con t nt. Th s

$$\frac{-d\ _A}{dt} = kc_A \qquad (1)$$

where $-dc\ /dt$ is the rate of decre e in c ncen trati n of A with time t The rate of change will decr ase as A is u ed up and its concentrati n de crea es but the rate will always be proporti nal to the concentrati n Thus if k has a alue of 0 01 p r minute 1% of A which is pre nt at any time t will rea t per minute O er l ng periods of time the concentration will be changing during the time interval and it is neces ary t int grate the equa tio Thus

$$k = \frac{2\ 303}{t_2 - t_1}\ l\ g\frac{c_A}{c_A} \qquad (\ )$$

where c_A is the c ncentrat on at time t_1 a d c_A is the concentrat on at t me t_2 Th it i po ibl to determine the r te constant k from the meas rements of the concentrat on of A at two d fferent times When th rate co stant has been valuated by ex perim ntal m asurem ts or by theor tical c lc la t ons it is po ble to calculate accurately the con *centrat on c_A* at any l ter time when it is known at one time Frequently the known concentrati n c_A i taken as the init al concent at on at t ring at zero t me

O d r of reacti The order of re cti n d pends on the expon nt of the conce tration which deter m ne the rate f the reaction Thus in Eq (1) the reaction i first ord r In a ther type of reaction which depe d on the collisi n of tw m lec le $A + A \rightarrow A_2$ the r t i g n by th formula

$$\frac{-dc_A}{dt} = k\ _A^2 \qquad (3)$$

Such a ct is c ll d second rder reaction If the reaction i $A + B \rightarrow AB$ the rate f the re- action may be gi en by the relat on

$$\frac{-dc_A}{dt} = \frac{-dc_B}{dt} = \frac{dc_{AB}}{dt} = kc_Ac_B \qquad (4)$$

The re cti n rate is fi t order with re pe t to A d fir t order w th spe t t B l t the er all re- ct on ate is said to b seco d orde The rea tio *rd s equal to th* sum of the expo ents of the o e t t ns of all the re cti g m t rial In a first-o der e ctio k is me ely a rat o a d i i *depend nt f the u ts of* c nce trat on ed I a econd ord r eact which depend on th prod ct of the c centrat ons the c n tant k ncl d *term f r th conc ntrat n* Its numerical al e depe d on the ntrat n u its used su h s mole pe l ter

When the *t me interval is* l ng t i n ce ary to u i teg ated f rmulas Thus Eq (3) bec mes

$$k = \frac{1}{t}\frac{x}{a(a-x)} \qquad (5)$$

and Eq (4) bec m s

$$k = \frac{2\ 303}{t(\ -b)}\ l\ g\frac{b(a-x)}{(b-x)} \qquad (6)$$

In the case of Boltzmann statistics use of Eq (1) (2) (10) and (24) gives

$$j = \frac{Ne^2\tau}{m} E \qquad (25a)$$

The conductivity $\sigma = Ne\ \tau/m$ cannot be compared with experiment unless the relaxation time τ is known In the Fermi case the evaluation of Eq (24) is facilitated by observing that $\partial f_0/\partial\epsilon$ has a δ function character Call $A = e^{\beta}$ so that Eq (5) reads

$$f_0 = \frac{1}{e^{\beta(-)}+1} \qquad (25b)$$

It is easy to show from (25b) that

$$\frac{\partial}{\partial\epsilon}\frac{1}{e^{\beta(\epsilon-\mu)}+1} \cong -\delta(\epsilon-\mu) \qquad (26)$$

for sufficiently low temperatures This allows the immediate calculation of Eq (24) also for the case in which the relaxation time depends on the velocity

Viscosity and mean free path One of the early successes of kinetic theory was the explanation of the viscosity of a gas Strictly speaking this is again a transport property and as such it should be obtained from the Boltzmann transport equation (20) It is possible however to give an elementary discussion Consider a gas that is contained between two walls or plates the lower one ($y = 0$) at rest and the upper one constrained to move with a given velocity in the x direction (see Fig 2) A force is necessary to maintain the constant velocity of the plate This force is given by

$$X = \eta A \frac{dv}{dy} \qquad (27)$$

Here dv/dy is the velocity gradient and X is the viscous force (also sometimes called the shear stress) on the area A which is perpendicular to the diagram (X is the component of X in the x direction) Equation (27) defines η the viscosity

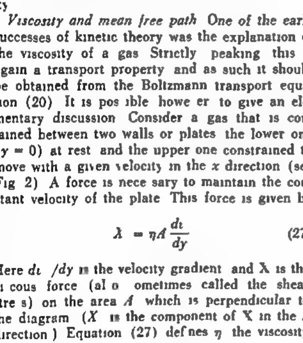


Fig 2 Explanation of viscosity The plate at $y = h$ moving with velocity v and the plate at $y = 0$ is stationary The horizontal component of velocity of the gas molecules es from 0 at $y = 0$ to at $y = h$ Momentum must therefore be transf d across S by the rtical component f velocity

coefficient The physical reason for this force term from the fact that molecules above the surface S have a greater flow velocity than those below this surface (This will certainly be true on the average) Thus molecules crossing from above to below will carry a larger amount of momentum in the positive x direction than those crossing from below S upwards Hence the net effect is a transport of momentum in the x direction across the surface By Newton s second law this will yield a force The computation can be carried out in this manner Consider an area in the x plane The number of molecules passing through per second is fv_yA where f is the distribution function The amount of momentum transported in the x direction is (per collision) $fv_yA\ mv$

The force per unit area is the sum of these terms

$$fv_yv\ m \qquad (28)$$

For the evaluation of this sum the notion of mean free path is useful The mean free path is the average distance traveled by a molecule between collisions and is usually designated by λ To investigate this entity imagine each molecule to be a hard sphere with radius a If a molecule moves with average speed $\bar{c}$ it sweeps out a volume $4\pi a\ ct$ in time t If there are $n = N/V$ molecules per unit volume the number of collisions per second is given by the collision frequency

$$= n4\pi a^2\bar{c} \qquad (29)$$

For a typical gas (oxygen) under standard conditions $n = 3 \times 10^{5}$ $\bar{c} = 4\,5 \times 10$ cm/ ec and $a \cong 1\,8 \times 10$ cm Hence numerically $z = 5.5 \times 10$ collisions/sec The average distance between collisions that is the mean free path is

$$\lambda = \frac{ct}{n(4\pi a^2)ct} = \frac{1}{n(4\pi a^2)} \qquad (30)$$

Numerically $\lambda \cong 8 \times 10$ cm This discussion is of course exceedingly crude Making the calculation on the basis of a Boltzmann distribution gives

$$\lambda = \frac{1}{\sqrt{2}\,n(4\pi a^2)} \qquad (30a)$$

Using similar methods it may be shown that the distribution of the mean free path (that is the number of molecules whose mean free path lies between x and $x + dx$) is

$$dN = \frac{N_0}{\lambda}e^{-x/\lambda}dx \qquad (31)$$

There is an interesting connection between the mean free path and the relaxation time introduced previously It should be stressed however that this connection follows from a qualitative discussion not from a rigorous calculation One would guess that

$$= \lambda/c \qquad (32)$$

Th m ans that a relaxatio time de cribes the decay f om a tate so n ar an equilibrium state th t hen the m lecul have tra lled (on the a er age) on mea free path the equ librium i reestabli hed St ted d fferently the n nequil brium st t s, on the average, one collision per mol cule remo ed f om the equil b ium state.

Expre io (8) may n w be evaluat d in terms of th mean free path a

$$\text{Force pe unit area} = \tfrac{1}{3}nm\lambda c\frac{d}{dy}$$

From th s, the isco ity coefficient foll ws directly

$$\eta = \tfrac{1}{3}nm\bar{c}\lambda \qquad (33a)$$

Introdu ing the m n free path as gi b Eq (30) ne sees th t

$$\eta = \frac{1}{3}\frac{mc}{4\pi a^2} \qquad (33b)$$

Th rema kabl *result is that the isc sity is in* deed independent of the pre ure Since

$$c = \sqrt{8kT/\pi m}$$

the is o ty d pe ds on the tempe ature but not n th press Th s somewh t intuit e result w s e of th fir t tr umph of k et c theory B th *spects of Eq* (33) re i good a ement with *sperime t* f r not too l w densit es η is in deed *ndep* d t f th pres ur η i also p oporti l to the qua e o t f th temperatu e

[M DR]

Bibliog phy R H Fowler *Statist cal Me han* ics 2d ed 1936 D Ter Ha El m t *of Sta tis ical M chan c* 1954 C. Kittel *El m tary Statist al Physic* 1958 e als STATISTICAL ME HA ICS

Kinetics (chemical)

The b an h f phy i al ch m st y c n erned with the *mecha* i m and ates f chem cal rea t on Th study of acti at on n rg es of *r ctions* s also a mporta t top in hem al k m s

Reaction rate The rate t which ch m cal eact t a u ed p or t wh h hem cal products *l rm d* s an imp rtant t p c part ularly gani hem try and b ch m try where ma y *d ff r nt* prod ts c b *ol ta* ned all (whi h a po *ibl* ac rd g t *th rm* dynami cal latio The p od t actu lly bt ned i det rmi d by the r l ti ates f th *c mpet* g r a t ons Th re f r a k wledg f r actio te s mp rt nt in c tr ll g hem al r a t o

Rat *t* i The p fic rat n tant k i u e f l cal l ting a t n at s t *no s c* en trations. If a impl h m l r a ti n $A \rightarrow B$ the r t of r *t on is d* tly p port onal to the entrat of A the p op t l ty t t k is c lled the pec fic act n r te c t nt. Thu

$$\frac{-d\ _A}{dt} = kc_A \qquad (1)$$

where $-dc\ /dt$ is the rate of decrea e in concentration of A with time t The rate of change will decrease as A is u ed up and its concentration decrea e but the rate will always be proporti nal to the concentration Thus if k has a value 0 01 per m nute 1% of A which i pr sent at any time t will react per m nute Over l ng period f time, the concentration will be changing during the tim interval and it is neces ary to integrate the equa tion. Thu

$$k = \frac{2\,303}{t_2 - t_1}\log\frac{c_A}{c_A} \qquad (\ )$$

where c_A the concentrati n at time t_1 a d c_A is the conce tration at t me t_2 Th s it is pos ble to determ ne the rate con tant k f om the m as rements of the concentrat on of A at tw d fferent times When the r te con tant has been eval ated by ex perimental mea urements or by theoret cal c lcula t ons it i possibl to calculate accurat ly the con centration c_{A_2} at any l t r t me when it is known t one t me Frequently the known concentrat on c_{A_1} i tak n a the initi l concentrati n starting at zero t me

O d of re ct on The rder f react on depend o th expone t f the concentrati n which *deter* mines the rat of the re ct on Thus in Eq (1) *the e cti n i first* rder In another type f react on wh ch dep d on the colli on of tw molecule $A + A \rightarrow A$ th e rate i g en by the f rmula

$$\frac{-dc_A}{dt} = kc_A{}^2 \qquad (3)$$

Such a re cti n is alled a econd-order react n If the e ction i $A + B \rightarrow AB$ the rate of the re ct o may be gi en by the relation

$$\frac{-d}{dt} = \frac{-dc_B}{dt} = \frac{dc_{AB}}{dt} = kc_Ac_B \qquad (4)$$

The re ction rate is fi st order with respect to A and fir t de with respect to B but the er ll re a ti n ate s said to be econd o de The *re ct on orde i equ l t* the um of th e po ents of the c *ntrat on* of all th e t ng m terial In fi *t-order rea ti n k* s merely a rat o and *i in depend* nt of the un ts of *oncentr t on* u ed In a s o d-o d r r a t on wh ch d pend on th prod u t f the c n e t ati ns th c n tant k i clude a term f r the c *nc ntr tion* Its numerical lue depend n the *onc ntrat* on un is used such as moles p l te

When th *time int rv l s l ng t i* neces ary to e int grat d f rmul Th Eq *(3) becomes*

$$k = \frac{1}{t}\,\frac{x}{(a - x)} \qquad (5)$$

and Eq (4) be m

$$k = \frac{2\,303}{t(a - b)}\log\frac{b(a - x)}{(b - x)} \qquad (6)$$

where a is the concentration of A and b is the concentration of B at the start of the reaction when $t = 0$ and x is the change in concentration during time t

Third order reactions involving three substances A B and C are known but they are rather rare The rate of the reaction is proportional to the product of the concentrations of A B and C

Zero order reactions given by the formula

$$\frac{-dc_A}{dt} = k \qquad (7)$$

are known In these the rate is independent of the concentration and is constant over a long period of time Such zero order reactions are found in photochemistry where the intensity of light rather than the concentration is the rate determining factor They are found also in saturated solution where the concentrations of the reacting materials are kept constant by the solution of more of the solid

If the order of a reaction is known it is a simple matter to calculate with the formulas just listed the amount of reactant remaining or the amount of product formed at any time If the order is not known it must be evaluated from experimental data For example in the rate expression for the reaction A + B

$$\frac{-dc_A}{dt} = \frac{-dc_B}{dt} = kc_A{}^m c_B \qquad (8)$$

it is necessary to evaluate the exponent m and n Usually they will not be the whole numbers 1 2 or 3 but rather numbers such as 1 3 which then do not give first second or third order reactions The reaction with fractional exponents involve several reaction which take place simultaneously

In evaluating these exponent the data may be substituted into formulas to determine if a first second or third order formula will agree with the experimental data Also the order may be determined by graphing The reaction is first order if log c_A gives a straight line when plotted against time second order if $1/c$ gives a straight line and third order if $1/c$ gives a straight line provided all reactants start with the same concentration A zero-order reaction gives a horizontal line when concentration is plotted against time The order of each reactant can be determined also by increasing its concentration and measuring the effect on the reaction rate while the concentration of all other reactants are kept constant or are present in large excess

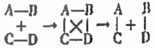
Experimental measurements Measurement of reaction rate are made by determining the concentrations of reactant or product as a function of time In a closed system samples can be withdrawn and analyzed immediately (or chilled quickly) so that the concentration does not change after the time of sampling The analysis may be carried out by chemical means such as titration or by physical measurement of such properties as light absorption refractive index or volume

If there is a change in pressure of a gas, electrical conductance volume of a solution electrical conductance or other physical property the course of the reaction can be followed in the whole reaction vessel without withdrawing samples If only one of the reactants or products absorbs light of a given wavelength the changing concentration may be followed by measuring the absorption of light

In some reactions the rate is determined conveniently by passing the reacting material in a stream through the reaction chamber and determining the concentrations before and after entering the chamber The time is estimated from the rate of flow and the volume of the chamber

Activation energy *Energy must be supplied to* prepare the molecules for reaction Otherwise the reactions would take place almost instantly In ordinary thermal reactions this extra energy is provided by collisions with molecules that are moving at very high velocities Energies of about 10-100 kcal/mole are usually required to activate the molecules in reactions which proceed with measurable rates

The activation process usually involves the weakening or breaking of a chemical bond Thus in a typical reaction



(9)

energy is required to activate the molecule AB and CD and bring them so close to each other that there is a force of attraction exhibited between all the atoms *The activated complex which results* may break up in different ways for example into the product AC and BD

Complex molecules with many atoms may be regarded as composed of many different atom pairs held together either by electrical charge or by electron pairs and the energies required to loosen or break these pairs and to move the atoms *around* varies greatly in different chemical reaction

If the activation energy is low there are many effective molecular collisions and the reaction is fast If the activation energy is high only a small fraction of the molecules will be moving fast enough to give sufficient energy on collision to activate the molecules and bring about the reaction Then the reaction is slow The distribution of molecular velocities at a given temperature is given by the Maxwell Boltzmann distribution

When the temperature is raised the average kinetic energy of the molecules increases at a rate proportional to the absolute temperature but the number of molecules with very high velocities increase very greatly Accordingly a chemical reaction proceeds very much more rapidly when the temperature is raised The effect is so large that most chemical reactions in the neighborhood of room temperature will double or treble in rate for a 10-degree rise in temperature

The Arrhe s eq t o g s the relat n be wee ti n rate and temperature thus

$$k = se^{-\Delta H_{act}/RT} \quad (10)$$

h e k i th pec fic r ction rate con tant e i h b e f n t ral logarithm (2.71828) R i the g s t t, a d T s the ab ol te t mper ture The con t t ΔH i wn a th he t f act t n and the c n t t s is called th fr q y f ctor

A d g t thi q ati n when the l g ithm of the pec fic r t c n ta t is pl tted again t the rec p oc l f th b l te tempe ture traight l e produ ed Th lope f this l e multipl ed b the g c sta t R a d th c n r fa tor 2.303 t rt l g o t t l g t gi e th al e f th t f a ti at n Th r l t hold m rk bly ll f mo t chem cal r ct e e f r mpl r ct n An x mple i h wn Fig 1 f the dec mpo it n f nit oge pent d Wh th t t a e e l ted b m ur g k at two or m d ffe t t mp at es it i po ibl t cal lat the p ifi r cti n r te n ta t at ny t mpe t r wh ch th eq t h ld

The E g q ti n s mil r t th mpiri l Arrhe u qu t n b t it s b ed n t tist cal mech nd i m re xa t It tak th f rm

$$k = \frac{RT}{Nh} e^{\Delta S_{act}/R} e^{-\Delta H_{act}/RT} \quad (11)$$

h re th dd tio al t rms e defi ed f ll w ΔS_{act} i th e t opy of cti ti N i the A g dr n mbe 6 0 × 10 d h Plan k s on tant, 6 6 × 10 erg e The e t py f act a ti n s b d t rmined in mple e ti s f om t t t l mecha ng d t f pect osc py a d m lecular stru t e Th t rm RT/Nh h s a alu f abo t 10 ec n r mt mp r t e

Predict on of reaction rates R ir p dict ns e d ffi lt but few ge l rules r a a l bl f th mpl r t s. Th h f diffi ulty l es i the f t th t m st bem al a t s e c m pl x a d i l ld ffe e t r a t o t king pl ce multa eo ly F rt t ly m t of th r

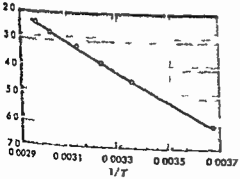


Fig 1 Pl t of th A h q t f th d m po t F 9 l d Loga thm of th p c f eact t pl tt d g t th p l f th bsolut t pe tu

actions that make up the omplex reacti n r th m el s s mpl unim lec l r reacti ns wl ich in l e only ne m lecule and f llow the f r t-order rate equation or b m lecular reacti n wl ich in ol e tw m lecules and gi e a ec nd ord reac ti n

In simple u im lec l r reacti the fr quency factor s has a alue of about 10 ec If it i much l rger a h m r action i p l al ly pres nt (s CHAI REACTION CHE IICAL) If it i mall r a cha ge i ntr py i prob bly i l ed in a ti ti n In a mple b m l ul r r acti n wl i h g es a sec d-order re ti n r te the fr q ien y factor i cl to the freq ncy f m lecular ll t a q ntity whi h can b al l ted l y th ki neti theory fr m kn wledg f th con trat n f m l ule a d th m lecular d ameter I l molecular eacti n t l g ompl x m lec les the cal ul ti of ll i ns i n t ig f t and it i neces ary t alc l te the r tropy of act ati n a i d cated i the Eyri g equati

Th heat f a ti ati n n l d t rmined exp r im tally from th rates at two t mp r tur nd ttempt h e been mad to est mate th m n th ba of m le lar co tant

In th est mati n l a t n gy potent l nergy urs ar som t me d w in whi l the energy h lding a p ir f t m t g ther pl tted aga nst the i ter t mic di t n Th e i min m m i th urve at the int rat m c di t nc the mal m lec l d th en gy r q r me t r e h rply a th t m are f r ed cl t g th r A the t ms ar pulled f rtl er p rt the en rgy re q em t n ea e al o b t fi lly n inter t mic di t n i ea hed whe th at m br k p rt gi ing a h ri nt l l nd i d t g th t n furtl en gy i equired f furth parati The h p f thi curve can b det rm ed fr m pec tr c pi data and qu ntum n mb r If thes po t ti l e gy urve c n be pl tted in three d m n n w th n gy l ng the e ti al x d i ter t m d t nc betwe th t d ff r nt pa r of t ms l g th h r tal x a p t nti l e gy s face bt i d Th he ght of the l we t n gy pa pa t g tw v lleys c re p nd ng t t ble actant a d p d i a m ue of th a ti ti n nergy

Th typ f calcul ti n f r acti ti n rgy been att mpted i a em empi ic l m thod pro p sed by H nry Ey i g It n l er impl fied lc l t o d n th e ergy req d to b eak the t m p r bo ds a determ ed fr m c l ime try r fr m p ct py n the ibr t on fre qu n y d t m ed f m inf a ed pect o py d n th te t m d t ce i th stabl mol le A k wledg of the type of b di g i ec ry th t i th fr t o f th bi di g en gy wh h le t stati atur d the f a t wh h h m pol r lectr p b d ng The lt ha n t h ry ati f ct ry

I b mole ul ti ns d ng t a crude mp l rul pr pos d by J O H hi lde the t o e gy ro ghly eq al t 28% of

the energy required to break the bonds of the two reacting pairs of atoms

In endothermic bond breaking reactions a lower limit can be placed on the heat of activation It is *at least as great as the energy required to break* the bond If the rupture of the bond produces atoms or free radicals which recombine without the requirement of activation energy the activation energy is equal to the energy required to break the bond

In exothermic reactions there is no relation between the heat evolved and the activation energy It is thus necessary to rely on experimental data or rough estimates based on molecular structure or on the Eyring or Hirschfelder rules

Many chemical reaction rates are greatly affected by catalysts and by light and high energy radiation

Complex reactions These are chemical reactions in which more than one reaction is going on at the same time Simple first order reactions in which the rate depends directly on the concentration or second order reactions in which the rate depends on the square of the concentration can be described in simple mathematical terms However when several reactions occur simultaneously even if they are all first or second order reactions the mathematical description often becomes very complicated The most common types of complex reactions involve reverse reactions side reactions and consecutive reactions

Reverse reactions In this type of reaction products reunite to give the original reactants

$$A + B \rightleftharpoons AB$$

All reactions are reversible but usually the reverse reaction is so slight that it can be neglected Even if the reverse reaction is appreciable it can often be ignored in the early stages of the reaction before a sufficient amount of the products have accumulated

An example of a reversible reaction is the reaction between acetic acid and ethanol to give ethyl acetate and water

$$CH_3COOH + C_2H_5OH \underset{k}{\overset{k}{\rightleftharpoons}} CH_3COOC_2H_5 + H_2O$$

At first the rate of formation of ethyl acetate is given by the expression

$$-\frac{dc_{C_2H_5OH}}{dt} = k_1 c_{CH_3COOH} c_{C_2H_5OH}$$

but in later stages the formula is

$$-\frac{dc_{C_2H_5OH}}{dt} = k_1 c_{CH_3COOH} c_{C_2H_5OH} - k_2 c_{CH_3COOC_2H_5} c_{H_2O}$$

where k_1 is the forward reaction and k_2 is the reverse reaction It is possible to express k in terms of k_1 and the equilibrium constant K and to obtain by integration a *complete formula* for the complex reaction

Side reactions When these occur there are several ways in which the starting materials can react to give different products All are possible according to thermodynamics and the faster reaction *will predominate to give the larger yields of products* In the reaction of A with both B and C

$$A + B \xrightarrow{k} AB$$
$$A + C \xrightarrow{k} AC$$

the ratio of AB to AC will depend on the relative rates The rate expressions are

$$\frac{-dc_A}{dt} = k_1 c_A c_B + k_2 c_A c_C$$

$$\frac{dc_{AB}}{dt} = k_1 c_A c_B$$

and

$$\frac{dc_{AC}}{dt} = k_2 c_A c_C$$

An example of competing or side reactions is the nitration of chlorobenzene Three different reactions take place simultaneously to give products in which the NO_2 and Cl groups are adjacent in the benzene ring where they are separated by one carbon atom or where they are separated by two carbon atoms Most of the materials react to give the third product

Consecutive reactions In this type of reaction the product of the first reaction reacts to give a second product and this in turn reacts to give a third product

$$A \xrightarrow{k} B \xrightarrow{k} C$$

The rate at which B changes is given by the expression

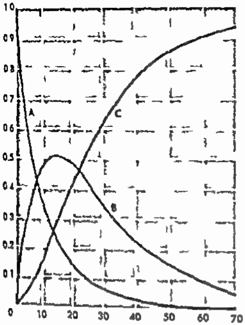
$$\frac{dc_B}{dt} = k_1 c_A - k_2 c_B$$

where k is the specific reaction rate constant for the decomposition of A and k_2 is the constant for the decomposition of B

Figure 2 shows a graph in which the quantities A B and C are each given as a function of time when $k = 0.1$ $k_2 = 0.05$ and 1 mole of A is taken at the beginning of the reaction The concentration of A decreases rapidly at first and then more slowly but always at a rate proportional to the concentration of A It approaches zero as the time increases *The concentration of B builds up* rapidly at first goes through a maximum then decreases and eventually approaches zero The product C is slow in getting started but after B has accumulated C increases rapidly and finally approaches 1 mole which was the original amount of A It is clear that the concentration of B is a complicated function of time

There are many types of still more complex reactions for example

$$A \xrightarrow{k} B \quad \text{and} \quad A + B \underset{k}{\overset{k}{\rightleftharpoons}} AB \xrightarrow{k} C$$
$$\downarrow k$$
$$C$$



F g 2 A mpl x react o illustrat d by co t e first-ord eact s

All t made up f imple u m lec lar d b m lecula r a tio comb ation d th d ffer tial equat ns can be w tt d wn s- tly In only a few c e h weve e the e d f f t l eq ti s b l d by i t g at on The t e pr s f m ny f th mpl x r act on cann t be t g ted but ca be l ed graphically o by modern math mat l c mput g machi es

It is l th t mpl react on the o der of th t m y b g e by f ct rather than by h le umbe i t g r nd these may change d ring th o rs f the r a ti n

Oft m b mol l r rea ti s i lv g th r ti b twee tw mol les th te app ar t be th t f fi t-o d re t n F mple th hyd ly f ethyl tat wate lut n th r te f the ti n ppear t depe d o ly o th c t t of th thyl a t t becau the sol t w te m ch la c ss that t does t pp a t ha g pp ably n am nt

Th t rmed te tep i a mpl e t b t d ed th th h lp f k n t me ment m d by ch ng the c t t n r wid lim t h b nging the t mp t r by t g pec fic at ly t d b b t r Somet m th con t t f a t rm d te b t e ca b f ll ed by m a g t ab pt f l ght at p rt ul w l ngt wh h t b l ed by th th m t ri l p nt

M ny h m l a t o mple F m pl mpl r t ti h th d t n f ga m t ri l by at lev ted t mp at s m y g th gh f ti s wh h p des l hol k t d d fi lly a bo d x de nd w t m d S CATA YSIS F EE RADI CAL HALF LIFE INHIBITOR (CHE ICAL) KI ETIC THEORY OF MATTER PHOTOCHEMISTRY I OTE TIAL BARRIER

[r p]

B bli g phy A A Fr t and R C Pear n *K t cs and M chanism* 19 3 K J La ller *Che c l Ki tics* 1950

Kinetics (classical mechanics)

Th t p rt f cl ical mechanic which deal with the relati betwe n the m ti ns of mat rial bodies and the f rc act ng upon them It i yn nym us with dynam cs of material bodie S e DYNAMIC

Basic concepts Ki etic pro eed by ad pting certain intu ti ely acceptal le c ncepts wl ich ar a ated with me ural le q iant tie The e e e tial conc pt and the mea rable q ntiti u ed for th r p cif cati n re a f llow

1 Space co f guration refer t the po ition and orie tati n f bod e i a ref rence fram ad pt d by the b erver It exp es ed quantitati ly by an a bitrar ly ch en s t of pace coordin t of which arte n and polar coordi te are exam ple All pace rdinate re t on th notion of di t n e m a reme t

2 D ation i expre d quantit t ly by time m asured by a clock or mparal le mech ni m

3 M ti n r f rs to ch g of c nfig rati n with time a d is expr ed by time r t of coordi ate *hange called velocitie* d time rate f v locity cha ge called elerat n The la ical a ump tio th t oordinates beh e a analytic fu ct n of tim p rm t repr ntati n f l t and accelerat n a fi t and d deri ati e re- spect ely of the sp ce oord at w th r pect to tim

4 I ert a n attr b te of bod es imply g th r ap ty t r t h ges f m t n A body in rt w th esp t to l n a m t n i den ted by *t m*

5 Mom tum tt f t proport l t b th the m s d l ty f a bo ly M m t m f li a m ti n i xpres d a th p od t f ma s nd li a locity

6 F er es t d gn te the i fl ence e c sed po th mot f a p rticul r body by oth r bodi not n es arily p cifi d A qua t tati co n t n betwe n the m t o f a body d th f c appl ed t xpres ed by N wt s e o d l w f mot on wh h s d se l l t

D t time nd ma r c mm nly reg rd d f d me t l all th dyn m l qu nt t b i g d f nabl int m of th m

Newton s second law A prim ry bj ct of J s l k t c th pred ct of th beh r f b d wh h a ubject t k w f es wh n ly n t al lues of th coord n tes a d m m nt l bl Th s ompl hed by u e f F pl fi t r g d by S I a N wto N wt s t tem t f th pr pl w e t i ted t th l m t of an de l d body alled ma p t l ha ng glig ble ext n o

The basic dynamical law set forth by Newton and known as his second law states that the time rate of change of a particle's linear momentum is proportional to and in the direction of the force applied to the particle. This statement, although special in form, serves as a basis for more comprehensive statements of the principle which have since appeared.

Stated analytically, Newton's second law becomes the differential equation

$$\frac{d(mv)}{dt} = F \qquad (1)$$

in which m represents the particle's mass, v its velocity, F the applied force, and t the time. This equation provides a definition of force and of its units if units of mass, distance, and time have previously been adopted. The classical assumption of constancy of mass permits Eq. (1) to be expressed as

$$ma = F \qquad (2)$$

where a represents the linear acceleration. A particle in physical space requires three cartesian coordinates, x, y, and z, to specify its position. Its linear acceleration is a vector with three cartesian components, the second time derivatives of x, y, and z. Equation (2) therefore equates two vectors, requiring equality of their components, expressed in detail by

$$m\frac{d^2x}{dt^2} = F_x \qquad (3a)$$

$$m\frac{d^2y}{dt^2} = F_y \qquad (3b)$$

$$m\frac{d^2z}{dt^2} = F_z \qquad (3c)$$

These are the Newtonian equations of motion of an unconstrained particle in space. If the three force components F_x, F_y, and F_z are expressed functions of the coordinates and time, the dependence of each coordinate upon the time is implied and can in favorable cases be found as solutions of the equations of motion in the form

$$x = x(t) \qquad y = y(t) \qquad z = z(t)$$

The primary objective of kinetics is achieved in the discovery of such functions.

One-dimensional particle motion. The motion of a particle which remains on the x axis, either because of constraint or initial conditions, is determined by Eq. (3a) alone when the solution is simplified by the absence of y and z. Such one-dimensional dynamical problems provide an attractively simple introduction to the subject. Examples are the motion of a body falling vertically subject to gravitational force and linear harmonic motion.

Two-dimensional particle motion. The motion of a particle remaining in the plane of the x and y axes is determined by Eqs. (3a and b), from which z is absent. Two-dimensional problems are reasonably tractable and include many of physical interest, such as the motion of a projectile (exterior ballistics) and of a body attracted toward a central point as in planetary motion. Solution of a two-dimensional problem is frequently simplified by change of variables which reduces it to a pair of one-dimensional problems.

Three-dimensional particle motion. All three equations of motion (3a, b, and c) apply to an unconstrained particle in space. Complete solutions are possible only when the functions expressing force components are relatively simple in character. Fortunately, many of the solvable cases correspond to important physical examples in which simplicity of the forces allows separation into one- and two-dimensional motion. Three-dimensional projectile motion without friction is an example.

Newton's third law. The behavior of systems composed of two or more interacting particles is treated by Newtonian dynamics augmented by Newton's third law of motion, which states that when two bodies interact the forces they exert on one another are equal and oppositely directed. The important laws of momentum and energy conservation are derivable for such systems (the latter only for forces of special type) and useful in solution of problems. The equations of motion for systems of more than two interacting particles in space are mathematically intractable in the absence of geometrical constraints or special initial conditions, but assumptions approximating the physical situation permit solution of many problems of physical interest. The principles of particle dynamics are transferred to extended bodies by regarding them as systems of particles subject to specified mutual constraints and mutual forces. See RIGID-BODY DYNAMICS; see also ACCELERATION; BALLISTICS, EXTERIOR; FORCE; GRAVITATION; HARMONIC MOTION; MASS; MOMENTUM; ORBITAL MOTION; VELOCITY.

[R.A.F.]

Bibliography: H. C. Corben and P. Stehle, *Classical Mechanics*, 1950; J. C. Slater and N. H. Frank, *Mechanics*, 1947; E. T. Whittaker, *A Treatise on the Analytical Dynamics of Particles and Rigid Bodies*, 1904.

King snake

Any of several species of the genus *Lampropeltis*, seven of which occur in the United States. This is a group of smooth-scaled, moderate-sized snakes, all of which are constrictors and are separated into distinct groups by a common scale pattern. However, the species are highly diversified in color. Best known is *L. getulus* of the southern United States. [illegible] there are nine recognized subspecies, the most common of which is the black form which is marked with fine specks of yellow. It is sometimes called the salt-and-pepper king snake. Other species are banded or blotched in gray, brown, black, and white. The milk snake, *L. doliata*, is typically [illegible] with [illegible] distinct

f rms, but us ally tr gl) banded with red bl k d y ll w and i ften nfu ed with tl e d dly c al ake (s CORAL SNAKE) The milk ke c mmo e t of the R cky Mo t in b t s hy a d eld m een

Th name king ke come from the hab t f me sp ies of att cki g and k ll g otl nak m l d g p so ous sp ies *See* SQUAMATA

[J D B]

Kingbird

A flycat her *Ty n ty n us* of the f mily Tyra nid e Th m famil r summer r ad de b d o r m ch of east n North Ame ica it is also f d i O eg N ad and New Me i It t sl te g a abo e nd wh te b low The cr wn of ad lt h s a c n led o nge p tch The tail i bl k t pp d by b nd of wh t The kingbird

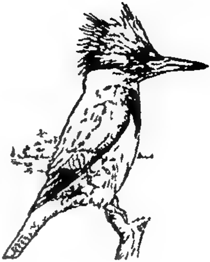
Th k gb d Ty ty l gth to 9 t (F m E L P lm F ldb k f N t l H st ry M G w H ll 1949)

p h f d h ubs f m wh ch it llies f rth t p ck in ects ut f th a r It metim u ly p y up h neyb e nd s f q tly ll d b m rti r bee b d b u f th h b t S FLYC TCHER PASSERIFORMES

[J D B]

Kingfisher

Any f 86 pe e f the t lly o mop l t fam ly Al ed n d e The s ly ne p s i th Unt d State *M g yle lcy* the b lted ki gfi h It m wh t m l r t th bl e jay b t l g r bl g ay b e d wh te b l w d has a gged t Th b lted k gfi h r n st n h l d g in t cal b k met m s q t a d s t ee f m w t It ee r m t f N rth Am ri a esti g p e a d w te f m th e t l t te uthwa d t Ce t l Am ri Th k ngfi h d f m a p ed pe h the w t d e t h m ll fi h w th gr t ecu r y It sol t ry d lw y fi he l nd w ll



Th b lt d k gfi h M g ryl alcy l gth in 14) t (F m E L P lm F ldb k of N t r l H t y M G w H ll 1949)

n t t ler te a tl er k ngf h r within it t r it ry *Se* CORACIIFORMES

[J D B]

Kinglet

Any on of se n spe ie of sm ll so gbird f th family Syl iid e the Old World warbl r Tw species o cu i N th Ame ica Fx pt f r th hum m gb d thes r the m ll t f all N rth

Th ruby-c w d k gl t R g l l d l l gth t 4⅕ (F m E L P lm F ldb k f N t l H s t ry M G w H ll 1949)

Am i a b d c ely h lf th f a p rrow They a e b g r m l l me f the m re l u e w rble s nd h e a ha cter stic n rv u twit h g f th w ngs s th y fl ab t thr gh t et ps o bu he The c wn f the head m y be l rl t y ll w d black y ll w a ge a d bl k

K gl ts n t th b l e d w te f m the t l t t s uthwa d S P SSERIFORMES

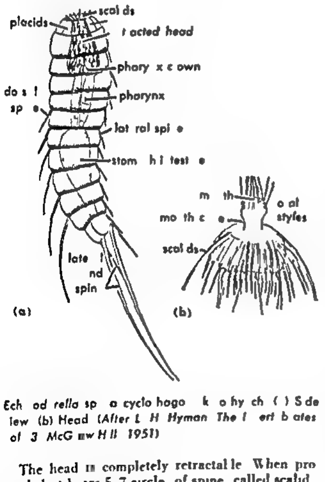
[J D B]

Kinorhyncha

A class of the phylum Aschelminthes consisting of superficially segmented microscopic marine animals lacking external ciliation. All members of the class are benthonic, so called because they generally dwell on mud bottoms in shallow water in the littoral zone.

Three suborders are generally recognized: Cyclorhagae, Conchorhagae, and Homalorhagae.

The body is completely enclosed in a transparent cuticle secreted by an underlying epidermis. As is the case among the Nematoda, the cuticle is periodically molted during growth. Three major regions of the body are recognizable: head, neck, and a jointed trunk. The apparent segments of the body are termed zonites; the head and neck each consist of one zonite. Except for one genus in which the trunk has 12 zonites, the usual number is 11.



Echinoderella sp., a cyclorhagous kinorhynch. (a) Side view. (b) Head. (*After L. H. Hyman, The Invertebrates, vol. 3, McGraw-Hill, 1951*)

The head is completely retractable. When protruded it bears 5–7 circles of spines called scalids.

The neck is covered by a varying number of large plates called placids. Only among the Cyclorhagae do the placids close over the end of the body when the head is withdrawn. Among the Conchorhagae the closing apparatus consists of a pair of lateral plates on the third zonite, while in the Homalorhagae it consists of a single dorsal plate and three ventral plates on the third zonite.

A pair of ventral adhesive tubes occurs on either the third or fourth zonite. Each of the re[maining trunk] zonites usually bears a pair of [...] terminal zonite may bear in addition a pair of large movable lateral spines.

The musculature is segmentally arranged. There are two pairs of longitudinal muscle bands, a dorsolateral and a ventrolateral. Anteriorly these form the retractors of the head. Protrusion of the head is accomplished by contraction of the ring muscles of the first two zonites and the paired dorsoventral muscle bands in the trunk zonites.

Locomotion is accomplished in the following manner: the head is protruded and the surface gripped by the scalids. The trunk is then advanced by contraction of the longitudinal muscles and the head is retracted. Repetition of this sequence results in creeping locomotion.

The nervous system consists of a brain which encircles the anterior end of the pharynx, a ventral ganglionated cord, and in addition ganglion cells in each zonite are located in the lateral and dorsal epidermal chords.

The mouth is terminally located on the mouth cone, which encloses a short buccal cavity. Posterior to the buccal cavity is a muscular pharynx. The pharynx is similar to that of the Nematoda and Gastrotricha but differs in being lined by a syncytial epithelium. The pharynx is followed by a short slender esophagus whose epithelial lining is continuous with that of the pharynx. The stomach intestine is a straight simple tube covered externally by a loose network of muscle fibers. The short endgut is separated from the stomach intestine by a sphincter. A second more posterior sphincter is also present. The anus is terminal.

The fluid-filled body cavity between the digestive tract and the epidermis is unlined and is presumably a pseudocoele or false coelom.

A single pair of protonephridial excretory organs is present in the tenth zonite. The flame bulbs are multinucleate and generally each contains a single long flagellum. Among the Homalorhagae a second short flagellum is present. The protonephridial canal, which leads to nephridiopores on the eleventh zonite, contains driving flagella. The pores consist of sieve plates.

The Kinorhyncha are dioecious. In each sex there is one pair of gonads. The genital pores are located on the thirteenth zonite. The ovary contains both ova and nutritive cells. A short oviduct extends from the posterior end of each ovary to the genital pore. The male genital pore is armed with two or three penial spicules which may serve as copulatory apparatus.

The early embryology of the Kinorhyncha is unknown. In the Cyclorhagae the egg hatches into a minute larva which lacks external evidence of zonites, head plates, pharynx, or anus. This larva passes through several successive stages, separated by molts, during which the number of zonites increases and adult morphology is attained. Among the Homalorhagae the first larva has 6–7 zonites and is in general a more advanced larva than that of the Cyclorhagae. The development of the Conchorhagae is unknown. See ASCHELMINTHES.

Kirchhoff s laws of electric circuits

Fundamental atural laws dealing with the relati n f currents at junct n and tl e oltages round a loop these la s are mmo ly used in the analy is and solution of n tw rk They m y be u ed directly to sol e ci cu t p oblems, and they fo m the basis fo n tw rk theo em used w th mo e complex net rk M y ye rs of e perience ha e pro ed the x ctne s of th se l ws

In the solution f ci cuit problems it is neces sary to identify the spec fic physic l pri c ples invol ed in the p obl m a d on the basi of them t write quat s expre sing the relati ns among the nknowns Physically the analysi f networks is ba ed on Ohm s law g ing the bran h equati ns Kirchhoff's ltage law g ng the loop voltage equ ti ns, and Kirchhoff's current law givi g the nod c irr nt equations Mathematic lly a netwo k m be sol ed when it is p s ble to et up a n m ber of independe t equ ti s equal t the number of unknowns. *See* CIRCUIT ELECTRIC NETWORK THEORY ELECTRICAL.

When wr t ng the nd pendent eq tio s current directi ns and olt g pola it es may be cho en arbitrarily If the equ tions are written with due g rd f r these arb trary cho ces the algeb ai s g of curr nt and oltage w ll take c re f them sel es.

Kirchhoff s voltage law O e way of stating Kirch h ff's oltag law i At ea h in tant of time th algeb a c um of th olt ge r is q al to the alg b a m f the olt ge dr ps both being taken in th s me d rect n rou d the cl sed loop

Th ppl ati of th s l w may be ll trated th th c u t F g 1 F r t, t s d able to on d the gnificance of a ltage ri e d ltag d p l t n to the urr nt ar w The f ll g defin t ns a ill t ated by Fig 1

A ltag rise n nt ed f g i g f m l 1 2 n th d ect n of the urr t arr w the pol r ity f om m u t pl Th s E i v ltag r se fr m l t 2.

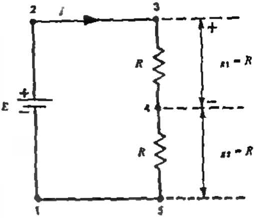
A lt g d op i e c u te ed f g i g f m 3 to 4 n th d ect n f th rr nt arr w the pol rity f m plu t min s Thus e $= R i$ s a l g d p f m 3 to 4

The ppl at o f Kirchh ff's ltage l w g es the loop ltag equ t n

$$E = \quad + e = R i + R i$$

In th n tw rk f F g 2 the ltag ur s ha e the m f qu ncy The pos t s fo the b h curr t I I and I e cho e rb t a ly a e th loop rr ts I nd I The ltage equ tio s f loop 1 d 2 c b wr tte g n ta t b ch urr ts st t n l op curr nt ph sor b h c rr t ph loop rts

The loop lt g qu t obta ed by ap plying K hh ff ltag l w t ea h loop s f l lo



Fg 1

Using in tanta eous bra ch currents

$$e_1 = Ri_R + L\frac{d_L}{dt}$$

$$e_2 = \frac{1}{C}\int i_C\,dt + L\frac{di_L}{dt}$$

Usi g instantaneou l p current

$$e_1 = Ri_1 + L\frac{d(i_1 + i_2)}{dt}$$

$$_2 = \frac{1}{C}\int i_2\,dt + L\frac{d(i_2 + i_1)}{dt}$$

Us ng ph or branch current

$$\mathbf{E}_1 = R\mathbf{I}_R + j\omega L\mathbf{I}_L$$

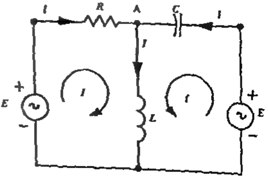
$$\mathbf{E} = -j\frac{1}{\omega C}\mathbf{I}_C + j\omega L\mathbf{I}_L$$

Usi g pha r loop currents

$$\mathbf{E}_1 = R\mathbf{I}_1 + j\omega L(\mathbf{I}_1 + \mathbf{I}_2)$$

$$\mathbf{E}_2 = -j\frac{1}{\omega C}\mathbf{I}_2 + j\omega L(\mathbf{I}_2 + \mathbf{I}_1)$$

Kirchhoff s current law Kirchhoff's current law m y b expre s d as follows At any gi en n t nt the sum f th n ta t neo s alues of all th cu rents fl w ng toward a po nt equal t the s m of th inst nta eous value f ll the curre ts fl wing away f om th p int."



Fg 2

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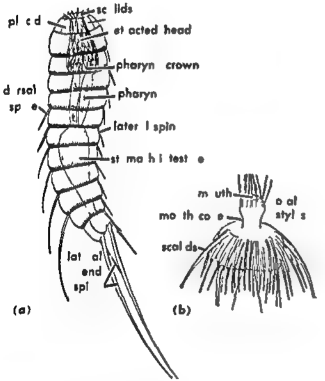

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[E.S.]

Kirchhoff s laws of electric circuits

Fu d m t l natural laws d al g with the relatio f currents t a ju ct on a d the v ltages arou d a loop these la are c mm nly u ed in the naly i and solution of netw rk They may be u ed d rectly t sol e c rcu t p oblem and they f rm the ba i for etwork theor m used with more complex net orks. Ma y year of exper e ce ha e pro ed the ex ctness of these laws

I the olut n of c cu t p oblems it is ne es sary to dentify th pec fic phys cal principles in l ed in the probl m and on the bas s of them to write equ ti s expre in g the relations among the u kn wns Phys ally the analysis f networks ba ed n Ohm law gi g the bra ch equat on Kirchhoff's ltage law g i g the loop voltage equati n a d Kirchhoff's current law g ing the nod rr nt equati M thematically a network may be l d when t s possible t set up a num be of independent equat ns eq al to the numbe of unknow s See CIRCUIT ELECTRIC NETWORK THEORY ELECTRICAL.

Wh n riting th ind pend nt equations current directio and olt g polar tie m y be ch en a bitra ly If the q ti ns are written with due r g d f thes rbitrary cho the algebraic gn of curre t and lt g will t ke care of them sel es.

Kirchhoff s voltage law O way of tating Kirchhoff oltag law i At e h in tant f t me th lg b m of the oltag i e is qu l to th lgebrai s m f the ltag d op both b ng taken in the same di t on a u d the cl sed loop

Th appl c t o f th s law may b illu trated with the ire t in F g 1 F rst, it des ble t co d r the gn fi nce of a v lt ge i a d ltage d p n elat t th rrent r ow The f llowi g defi ti n re Ilu trated by F g 1

A ltag m s e t red f goi g f om 1 to 2 in th d ect f th curre t a ow the p l r ty i f m m n t pl Th E a olt g rise fr m 1 t 2.

A lt g dr p o t ed if in g ng fr m 3 t 4 th dire tio f the current rr w th pol ty f m plus t m u Thu v = R a ltage drop fr m 3 t 4

Th ppli at n f Ki hh ff's ltage law g s the loop olt g q t n

$$E = \quad + v \quad = R \quad + R$$

I th n tw k f F g 2 the olt g ou h th ame f eq e cy Th p t f r the b anch urre t I I_L d I ar ch s n b t r ly e the loop rr nt I d I The ltag equ t f lo ps 1 d 2 n be wr tte u i g t nta eou b h e t st ta e s l op c rr ts ph so b h cu t pha r loop rre ts

Th loop lt g quati n a bta ed by ap pl g K hh ff lt g law t e l l op f l

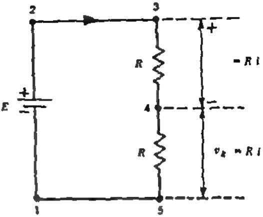


Fig 1

Usi g instantaneous branch currents

$$e_1 = R_R + L\frac{di_L}{dt}$$

$$e_2 = \frac{1}{C}\int i_C\,dt + L\frac{di_L}{dt}$$

Using insta taneou loop current

$$e_1 = Ri_1 + L\frac{d(i_1 + i_2)}{dt}$$

$$e_2 = \frac{1}{C}\int i\,dt + L\frac{d(i_2 + i\,)}{dt}$$

Using phasor branch curre ts

$$E_a = RI_R + j\omega LI_L$$

$$E_2 = -j\frac{1}{\omega C}I_C + j\omega LI_L$$

U g ph sor loop currents

$$E = RI_1 + j\omega L(I_1 + I_2)$$

$$E_2 = -j\frac{1}{\omega C}I + j\omega L(I_2 + I_1)$$

Kirchhoff's current law K r hh ff's *current law* may be pres ed s f ll w At ny g en insta t the m f the in t tan o val es f all the cur ents flowing t w d p nt is equal to the sum of th tant eo s al es of all the curre t flowi g way f m the po nt.

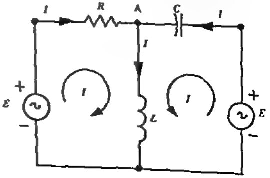


Fig 2

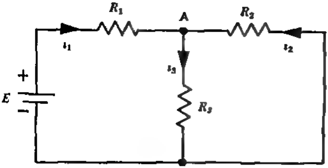


Fig 3

The application of this law may be illustrated with the circuit in Fig 3 At node A

$$i_1 = i_2 + i_3$$

The current equations at node A in Fig 2 can be written using instantaneous branch currents or *phasor branch currents*
Using instantaneous branch currents

$$i_R + i_C = i_L$$

Using phasor branch currents

$$\mathbf{I}_R + \mathbf{I}_C = \mathbf{I}_L$$

[K Y T]

Kissing bug

A name sometimes limited to a single species *Reduvius personatus* but usually applied to any of several members of the family Reduviidae order Hemiptera They are also called assassin bugs cone nose bugs or big bedbugs Several of these species may be found at times in houses and may inflict very painful bites They eat other insects Several species are known to be vectors for the trypanosome parasite that causes Chagas disease in South America and others are suspected as vectors for kala azar in India *See* CHAGAS DISEASE HEMIPTERA LEISHMANIASIS [J D B]

Kite

A tethered flying device that supports itself and the cable that connects it to the ground by means of the *aerodynamic forces created by the relative motion* of the wind This relative wind may arise merely from the natural motions of the air or may be caused by towing the kite through the agency of its connecting cable

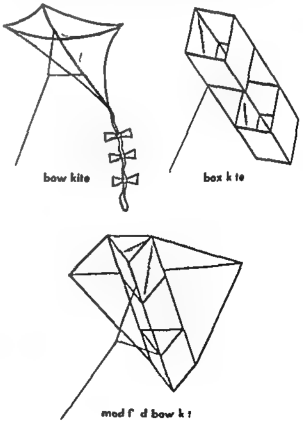
Kites take many forms the bow and box kites shown in the drawing are common in the United States In many countries particularly in Asia kites are frequently used in rituals and festivals their bizarre forms and shapes are traditional some having been developed centuries ago

The lifting force of all kites is produced by deflecting the air downward the resulting change in momentum producing an upward force To be successful a kite must have an extremely low wing loading (weight/area) so that it may fly even on days when the wind velocity is not high It must be completely stable since the only control available to the operator are the length of cable and the rate at which it is taken in or let out Efficient design requires that its lift to drag ratio be as high as possible

Experiments on the possible application of efficient aircraft type lifting surfaces in which most of the lift arises from the low pressures created by the air flowing over the upper surface have shown them to be too sensitive to changes in wind force and direction Under normal atmospheric conditions the use of this type of lifting surface results in a kite that behaves in a violent and unpredictable manner For this reason the higher drag associated with a surface from which the flow has separated is tolerated and the majority of the lifting force is obtained from pressure on the lower surface because stalled surfaces are much less sensitive to wind changes

Both the lift to drag ratio and the stability of the kite are functions of the length of cable The more cable released the more drag created This combined with the increase in weight being supported causes the kite to sag off downwind reducing the flight angle which is the angle formed between the horizontal and a line passing through the kite and the operator

Most kites with a properly located cable pivot point generally slightly ahead of the center of gravity demonstrate longitudinal stability Lateral and directional instabilities generally couple to produce violent motions The longer the cable the more these motions are damped Lateral and direc



Common forms of kite

t n l t bility are impr ed by the u f effecti e dihed l (th bow of the bow kit) d a fie lle tail h h p o de both d ectional t b lity and d mpi g [D C H]

Kiwi

A f e eral pecie f prim t e fl ghtle s ter restr l bird f th rde Apt rygiform There i b t o e l ing g n *Apt ry* l mited t New Z al d They h e l g l der b ll and ar c ered th loo hair lke f thers The w g i de- g t b ne t ctu e a well s in the ab n e

i kwi (F m E L P Im F ldb k f N t l H s- n McG o -H ll 1949)

l fl ght f ath Th p t r nge from ⅛ to 2¼ ft n l gth Th v t t orm nd n l N t c r with g e t pe d All th pec e e octurn l d d k l r The n t i a b le r th f t f t e nt n a ingl urge g S APTERYGIFORMES [J D B]

Klebsiella pneumoniae

A gr m egat rod h ped b c llu b l g g t h famil) E e b t a e e (ENTEROBACTE RIACEAE) It al o kn w F edland r b illu Th m oo gan m m t l s ally p ted, d p od es la g m unt of l my extr cell l m t al K pn m th u at agent f a p rt la ly ev p m n n n l d oc s lly m loc l ed p ul t nfe k n man d an m l It is ptibl to ther apy by ma v t b t (s ANTIBIOTIC) P esent (1960) p on l fies *Kl b ll* a g n sepa t f m *A b ct* [A J W]

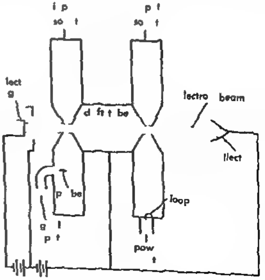
B bl g aphy E H m b a d P R Edwa ds *I t Bull B t t l K m T x* 10(2) 71 4 75 1960

Klystron

A type of lect on t b d f mplifi t o g t f d w es th m c ow g f f qu es It ut l ze the v lo ty m d l t p pl el t o f a b m b r d e- loc ty by th d o-f quen y (rf) olt g ppl ed a an p t g p f ca ity es n t D ft g a i th t ke pla th t th l ty variati ns are converted t current ariati ns and th current i turn induces an output a ro a gap to a cavity reson tor (ee ELECTRON MOTION IN VACUUM) The kly tro tub i a high gain narrow b nd tul e with po sible effic encies from l w t moder te a d a ds the lim tatio s of g id c n trolled tubes at the microwa e f e j en ies by mak ing use of tra it time effect f ele tron rather th n b ing degr ded in perf rma ce by th m See MICROWAVE TUBE

A chemati diagram of a mple klystr n tube i hown in F g l An ele tr n stream is prod ced l y a thermionic cath de and focu ed by the auxil ary lectrode of the electr n gun and in some high p wer kly tron l y f c ing magnet producing a mag et field n the d ect n f the electron t eam S gnal at m w e f eq en ies are ap- pl d t th inp it reso ant ca ty Th s produ e an rf v ltag ac s the inpu t gap (s met mes all d tle l t che) whi h i ft n gridded t local ze tl e rf fi lds acting n the electr n be m Thi applied rf ltage cau e lectro t l e ac celer ted by the f field for a half cycle and de- celer ted f the r m n g half cycl Th beam the enter a tant p tential drift r gi n wher th f t lectr t nd to catch up with the sl w ne th p d g l h f l arge in the beam t x t f om thi d ft eg n The b nched beam pa es thr ugh ec d gap (which i al fre quently gr dded) er wh ch an rf irre t in duced a d th p du es u f l outp t p wer by fl w g i th at d itp t cuit (som times lled th at h) Th elect on be m aft r pas- age th ugh the sec nd g p is coll ted on a col lect r lect de

T ill tr te the l ching ct o n a kly tron th Appleg te d a am f F g 2 is s mpl and u e- f l Thi a d t t m rs f th drift space the d te be g pr p rt al t d st nce l g



Fg l S h m t d g m of tw c ty kly tr mplf (m l p t E w)

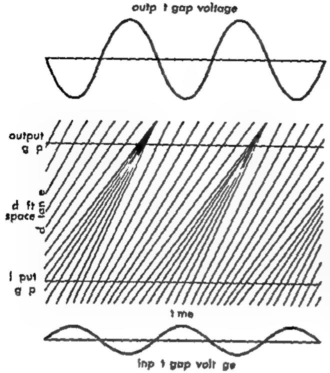


Fig 2 Distance time (Applegate) diagram for a klystron illustrating the bunching action in a drift space

the drift tube and the abscissa being proportional to time The curve for a given electron is a straight line in the field free drift space the slope of the line being proportional to the velocity at entrance Figure 2 shows a number of such lines each for a different electron entering at a different time and so with a different velocity depending upon the phase of the rf wave across the input gap at the time that electron passed through The diagram demonstrates how the faster electrons (greater slopes) catch up with the slower ones (smaller slopes) At some distance such as A marked by the dotted line definite bunches are formed so that an output circuit might be placed for induction of the

Fig 3 Wave shapes of current versus time for an idealized klystron neglecting space charge X bunching parameter indicates the degree of bunching

desired output Figure 3 shows pictures of the wave shape of current at various positions in the drift space for an idealized model as above It is to be noted that the current wave shape is rich in harmonics

The transfer admittance (analogous to the transconductance of a triode) of the idealized two-gap klystron is given by

$$y_m = \frac{j\theta I_0}{2V_0} e^{-j\theta} \left[\frac{J_1\left(\frac{\theta V_1}{2V_0}\right)}{\left(\frac{\theta V_1}{4V_0}\right)} \right] \qquad (1)$$

where V_1 is the effective ac gap voltage J_1 is a Bessel function of order one θ is the transit angle in drift space in radians I_0 is the dc beam current and V_0 is the dc beam voltage This transadmittance is ordinarily low compared with the transconductance of triodes and tetrodes so a high impedance is required in the output circuit usually a cavity type circuit As input gap loading is small the input circuit is usually a similar high impedance cavity circuit Both of these usually have a high quality factor Q which represents the ratio of energy stored to that dissipated per cycle leading to a relatively narrow bandwidth The value of transadmittance given by Eq (1) may be decreased by space charge effects in high density electron beams These effects cause both a longitudinal and transverse debunching of electrons Finite transit time across input and output gaps or the use of gridless gaps further decreases the transadmittance by the introduction of gap factors less than unity in the equation These latter effects also decrease the value of gap impedance so that smaller power gains are obtained

Circuit The resonant circuit used in both the input and output gaps is normally of the resonant cavity type (*see* CAVITY RESONATOR) Because of the desirability of keeping gap transit time to a low value the cavities are normally axially symmetric with a small gap in the vicinity of the axis where the beam passes Coupling from the cavity may be by loops probes or irises with the first of these most common

A given resonant mode of the cavity resonator may be represented by three parameter

f = resonant frequency

Q = quality factor = $2\pi f \times \dfrac{\text{energy stored}}{\text{average power loss}}$

R_{sh} = maximum shunt resistance across gap at resonance

For the output cavity which is coupled to a useful load the loaded Q_L becomes an important fourth parameter The Q is also related to the bandwidth of the circuit Δf between half power point

$$Q = \frac{f_0}{\Delta f} \qquad (2)$$

Klystron amplifier The b ıc two-ca ty t be of g l h be n desc bed as an amplıf r The lt ge g of ch a mpl fier ı gı en by

$$G = \left(\frac{P}{P_{in}}\right)^{1/2} = \left[\left(\frac{\theta I}{2I_{\theta}}\right)^2 \frac{R\ I}{2}\ ^2 \frac{2R_A}{I_1^2}\right]^{1/2} \tag{3}$$
$$= \frac{\theta I_0}{2I_{\theta}} R_A$$

h bandwıdth f the ampl fier ıs

$$\Delta f = \frac{f}{Q} \tag{4}$$

Th th g ı bandw dth product ıs

$$G\Delta f = \frac{\theta I_0 R_{sh} f_0}{2I_{\theta} Q} \tag{5}$$

H gh gain may be p od ed at the expense of band dth by ıng a circ t with h gher Q and c ers For a gı en tube the best g bandw dth p od t ıs obt ıned w th a cu t with the highest al e of R_{sh}/Q whı h ı frequently taken a a fig ur f merit f r kly tr n cır uits

Kly tro with gr ter ga bandw dth product than pos ble from two-c ty e s ıı may be made by u g add tıo al cav tıes a d tagger tun ıng among the ca t A mult a ıty klystron ı ıl lu tr ted ın Fıg 4 Bandwidths of 5% ha e been ob- ta ned f m h gh p wer kly tr ns of the multı ca ıty type

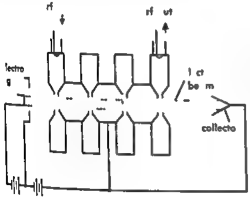


Fıg 4 Sch m t d g m f m lt ty kly t pl fi (vo m l p t h w)

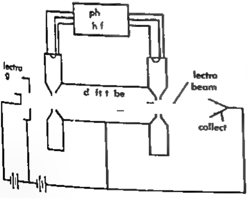


Fıg 5 Sch m n d g m f tw -c ty kly t oscıll t w h f db k b tw ı

Klystron oscillator The sımplest c nceptual klystro oscillator ıs obtaı ed by addı g exter l feedba k p th t the two-cavıty klystro ampl fi ll t ted by Fıg 5 Th ph se a d amo t of f dback mu t be pr p r for o ıllatı al th gh f q e cy a d powe level c shıft l ghtly t mpe s te f r m ll ıatı s from th ıdeal feedb ck o d tıo S h a two-c ıty scıll t r ery stable b t ı t ften u ed a t ı sually m bulky and tıve t dj tment than a m g t n f c mp ble p we le l

Reflex klystron oscillator Th s ıs mpl f l dev In th klystr n o ca ty t ke o th f t of both bu he a d tch Feed b k ı obt d by mea f a r pelle ltage n fl ctıng l ct de wh h et rns the b m to the a ty The f q y f th de e ı t able o ı th ge f bo t p ce t by cha g of th p ller lt ge lt ıs ed s f que cy m d l ted so r n scıll t fo u e n t m tı freq cy t l y tem Mo t eflex sc llator l w p w r d s (p w ı m llıwatt) a d u t bl f r l l llat s, alth gh me p od e pow of the d f w tts Ampl ficat n m lly pr d d f ll w ng br adb d t ges ıf h ghe p we l l a d ed a ın n FM t m tt

F gu 6 how th d g m f a typ l eflex kly t Th beam le th g the al way d p th gh the gle t ed ty wh ı el ty mod l t d th b n h f a two- ty kly tr mı g n rf lt ge s th

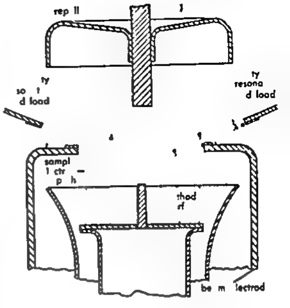


Fıg 6 Dı gram f fl kly t o o c ll to Thı d ıg ıll tr t s el ct path which mo d fl t m th gh the g p

gap The bunching action in this case takes place not in a field free drift region but in the retarding field region between the cavity and the repeller the latter being at a negative dc potential In this retarding region the fast electrons penetrate farther than the slow ones so that there may be bunching when electrons are returned to the cavity as shown by the Applegate diagram or distance time plot in Fig 7 If the phase of the returned bunches is correct the current induced in the cavity reinforces the original voltage building up an oscillation until nonlinear effects produce a limiting action

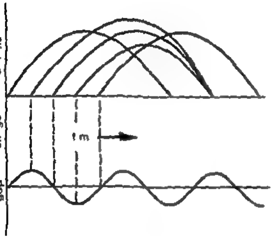


Fig 7 D stance t me (Applegate) d agr m fo a r flex klystron demonst at g the cond tion fo oscillat on

The correct phase for oscillation is found to result when the time of transit θ (out and back) of the average velocity electron represents an integral number of cycles N plus one fourth

$$\theta = (N + \tfrac{3}{4})2\pi \tag{6}$$

There are different electronic modes corresponding to the number of the integer N About each value of N oscillation will continue for a small region with variation of tran it angle A typical result of varying repeller voltage is shown in Fig 8 The

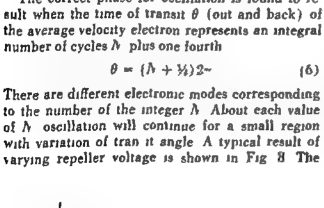


Fig 8 F equency and pow r o tput c rve o a f c t o of repeller voltage for a typ cal r fl klyst on demo strat ng ous electron c mode of o cill t on

mode with lowest N is at the highe t value of (negative) repeller voltage and is the broadest mode It may or may not be the stronge t mod d pending upon the strength of coupling to the load but if not the adjacent one will be the stronge t and higher order modes (lower values of repeller voltage) will decrease in strength The total tuning range is nearly the ame in all modes so the tuning rate in megacycles per volt is greater in the higher order narrower modes

If electrons are allowed to make more than one transit a hysteresis effect may be ob erved in that different tuning curves are obtained for increa ing or decreasing repeller voltage in a given mode The careful design can eliminate this po ibility in tubes for which it would be unde irable The sketch of Fig 6 indicates the design for collection of electrons after one transit

Reflex klystrons following these ba ic principles have been built for frequencies from 500 to 25 000 Mc [J R.W.H.]

Bibliography D R Hamilton J K Knipp and J B H Kuper *Klystrons and Microwave Triodes* 1948 A E Harrison *Klystron Tubes* 1947 J R Pierce and W G Shepherd Reflex oscillators *Bell System Tech J* 26 460–681 1947 R H Varian and S F Varian A high frequency oscillator and amplifier *J Appl Phys* 10 3 1 327 1939 D L Webster Cathode ray bunching *J Appl Phys* 10 501–508 1939

Knudsen number

In fluid mechanics the ratio l/L of the mean free path length l of the molecules of the fluid to a characteristic length L of the structure in the fluid stream When the mean free path of the fluid particles is short relative to the size object being considered the fluid can be treated as a continuum (see FIELD THEORY CLASSICAL GAS DYNAMICS) If the path length between molecular encounters is comparable to or larger than a significant dimension of the flow region the gas must be treated as consisting of discrete particles (see STATISTICAL MECHANICS SUPERAERODYNAMICS) The u ual cla sifications of flow according to Knudsen number are as follows for $l/L \leqq 0.01$ the flow can be dealt with by the method of gas dynamics for $l/L \sim 1$ the behavior is termed slip flow for $l/L \geqq 10$ the beha ior is termed free molecular flow or rarified gas dynamics [F.H.R.]

Koala

An arboreal marsupial *Phascolarctos cinereus* found in the eucalyptus fore ts of Au tralia It i ometime called the nati e bear koala bear or teddy bear and along with the kangaroo ha be ome a symbol of Australia It is gray above had ing to y llow b below The adult is ab ut 3 ft long It breed only every other year and the single offspring rides on it m th r s back until it i about a year old A in other mar upials the young are born after a hort ge tation peri d are quite

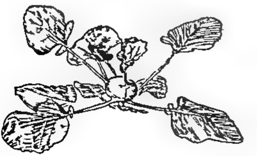
K l (F m E L P lm F ldb k f N t l H s- t ry McG -H ll 1949)

sm ll a d h lple nd mpl te the de lop- m t n abd m n l p h Th food f the k ala m d pent ly f th l f r s pecie f c lypt t e S e EUCALYPTLS MARSUPIA LIA

[J D B]

Kohlrabi

A cool e o ben t l c u sf r (*B a ul p a d B l a a l p*) of n rthern Eu p an rg b l g n t th pla t d P p l K hl b g wn f r t t n pl k e l ged t m h h u lly ate k d g t bl K hl b G rm n w d m ng bb g t rnip nd r flect t m la ity n ta te d ppear e t both get ble C lt l p a t ces f k hlr bi simil r t th s d fo turn ps. Wh t V e a d P pl V e r pop l t t H t g whe th l ged t m 2 3 d am te u lly 2 m th



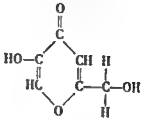
K hl bi (F m L H B l y d Th St d d Cy lo- pedia f H rtic lt l 2 M m ll 1937)

after plant ng A comm n cooked egetal le m Eu rope e pecially Germany kohlrabi s of min r im p tance in the United States *See* CABBAGE PAPAVERALES TURNIP VEGETABLE GROWING

[H J C.]

Kojic acid

An rga c a d 5 hydr y 2 hydroxymethyl y pyro wh h has been pr duced n an experi me tal b sis by fermentat n There at p e e t n ind trial u f k jic a id The compo d ha the f llow g t ct ral f rmula



Sever l spe ies of fil me to f ngi of the genu *Asp gillus* c n produce th n ncarb xyli ri type c d f m a s c rbohydr tes Sel cted tra bel gi g t the *A p g llus fl s o y* g p g th h gh t we ght y ld prod i g 50-65% of gl c e til ed A medium c nt ng mi eral s lt and 10-25% c mme cial gl c e adju t d t pH 1 8-2 0 The pH of the med um e tic l Th med m n ocul ted with p e r my el m of the m ld nd c t lly ae ated a d g tated nd ubme ged ndit for 5 days Th g t m l pr d es good yield the al wer u fa e t ay p oces Prod ct on f koji c d f ll wed q a t t t ly by the red c l r it gi s with f r c hl r de *Se* INDUSTRIAL MICROBIOLOGY

[J W F]

Kolbe hydrocarbon synthesis

The pr d t n f n alkan by th el ctr lys s of a wat l ble alt f arboxyli c d The c r b yl t s r d h ged at th node y eld g a bo d de nd lkyl ad cal wh ch c uple t f rm the tu ated hyd rbo Hydr gen i lib- t d t the th d

$$2RCOONa + 2H_2O \rightarrow RR + 2CO_2 + 2NaOH + H_2$$

Good y ld f lk es r obta ned w th th t aight ch a d nt n ng 5-18 c rbon t ms. Alke r the than lk nes a f rmed f the ac d c nta a lkyl b n h t the c rbo t m dj e t t the a b yl gr up th t s t th α p st n f th a d S ALKANE

[L S]

Krebs cycle

A eq n of nzymati e tio th t n l ed n th o d t m t bol m f m ny rgan m e p lly th th t carry t r p at on Th y l i al wn th t d cy le d the t c b xyl d y le Thr gh th s que p thway th two-c bo etyl t

$$\overset{O}{\overset{\|}{(CH_3C—)}}$$

an important metabolic intermediate derived from a variety of substrates can be oxidized to two molecules of CO_2 In aerobic metabolism two molecules of oxygen are u ed for this oxidation Organic acids containing four five and six carbons are formed in the course of the oxidation These are consumed and regenerated continually through the operation of the entire sequence Hence this oxidative pathway is a catalytic mechanism which operates in a cyclic manner and is known as the citric acid cycle because this tricarboxylic acid is one of the metabolic intermediates The cycle is also named after H A Krebs who recognized its functional role *See* METABOLISM

There are four oxidative steps in the cycle In each of the e two atoms of hydrogen or two protons and two electrons are removed from the substrate In aerobic respiration the electrons are transferred to molecular oxygen through the cytochrome system of iron porphyrin enzymes Energy rich phosphate bonds in the form of adenosinetriphosphate (ATP) are generated in the course of electron transport which therefore serves as the major source of energy for cellular metabolism Beside serving as a means for the complete or terminal oxidation of organic substrates which can be converted to acetyl fragments the reactions of the

$$HOOC—CH_2—\overset{O}{\overset{\|}{C}}—COOH \quad + \quad CH_3\overset{O}{\overset{\|}{C}}—$$

Oxaloacetic acid + Acetyl group of acetyl coenzyme A

(1) ↓

$$COOH—CH_2—COH(COOH)—CH_2—COOH$$

Citric acid

(2) ↓

$$COOH—CH{=}C(COOH)—CH—COOH$$

cis Aconitic acid

(3) ↓

$$COOH—CHOH—CH(COOH)—CH_2—COOH$$

Isocitric acid

(4) ↓ −2[H]

$$CO_2 + COOH—\overset{O}{\overset{\|}{C}}—CH_2—CH_2—COOH$$

α Ketoglutaric acid

(5) ↓ −2[H]

$$CO_2 + COOH—CH_2—CH_2—COOH$$

Succinic aci l

(6) ↓ −2[H]

$$COOH—CH{=}CH—COOH$$

Fumaric acid

(7) ↓

$$COOH—CH_2—CHOH—COOH$$

Malic acid

(8) ↓ −2[H]

$$COOH—CH_2—\overset{O}{\overset{\|}{C}}—COOH$$

Oxaloacetic aci l

Krebs cycle are used by the organism for the bio synthesis of important cell constituents which ca be derived from the metabolic intermediates partic ipating in the cycle The principal reactions of th Krebs cycle which will be discus ed below are out lined in the following diagram in which the oxida tive steps (dehydrogenations) are indicated by th symbol −2[H]

(1) The acetyl group which may be deri e from pyruvic acid or from other metabolic inter mediates or substrates enters into the cycle a acetyl coenzyme A (acetyl CoA) The so-calle condensing enzyme catalyzes the tran fer of th acetyl group to the four carbon compound oxalo acetic acid with the formation of the ix carbo tricarboxylic acid citric acid and the liberatio of CoA

(2) and (3) Citric acid is dehydrated to cis aconitic acid which is then rehydrated to i ocitri acid Both the e reactions are catalyzed by th enzyme aconitase

(4) Isocitric acid is next oxidatively decarbox ylated to yield CO and the five carbon compound α ketoglutaric acid by enzyme sy tems known a isocitric dehydrogenases Depending on the bi logical source of the enzyme either diphosphopyri dine nucleotide (*DPN*) or *triphosphopyridin* nucleotide (TPN) may act as the coenzyme an immediate hydrogen acceptor for this reaction There is evidence that an unstable intermediate oxalosuccinic acid is formed in the cour e of th reaction

(5) *α* Ketoglutaric acid is then oxidized and de carboxylated to yield the four carbon compound succinic acid This involves a equence of reac tions in which DPN serves a the hydrogen accepto and inorganic phosphate is taken up with the for mation of ATP from adenosinedipho phate (ADP) The first tep catalyzed by the *α* ketoglutaric de hydrogenase system requires DPN and CoA Th products are CO_2 reduced DPN (DPNH) an succinyl CoA In the next tep the P enzyme de compo es the succinyl C A with the imultaneou formation of ATP from inorganic pho phate an ADP Succinic acid is produced and CoA i re generated

(6) and (7) Succinic acid is next oxidized to fumaric acid by the enzyme succinic dehydrogena e and fumaric acid is hydrated to malic acid by fumarase

(8) Malic acid is oxidized to oxal acetic acid b the enzyme malic dehydrogena e with the c ncom itant reduction of DPN Th i xal acetic acid i regenerated through the entire equence of reac tions of the cycle and l ecome a ailal le for re acting with acetyl CoA

The enzymati reacti ns of the Krel cycle are imp rtant not only as a s urce of energy f r li ing cell b t al o as a so irce of e ential metabolic intermediate which er e a starting material f r bi ynthetic proce s Thu *α* ketoglutaric acid l e me aminat d to yield the ci l glutamic

a id This compound in turn tak p rt in the s thes f ther amin ac d Oxal acetic acid on erted to a parti a id whi h is al o a pre ursor f a numb of am o acids a well as of prim d [redacted] Some of th i te mediates of the kr b cycl ar ex reted by the cell Citr c ac d f e ampl pp a s i the body fluid of an als and, und m cond t on is a m jor product of ll met bol sm I molds Sim larly α ketoglutar c f m c, a d succinic cid are excreted by some mic oo gan m

Becau e the n mo al f the int med ate in the kr bs ycl through b osynthes s o excretion de str ys th i tegrity of the cycl as a catalytic mecha i m f th o idatio of acetyl unit li ing y m mu t p ss au il ry mech ni ms f r p n h ng th r upply of uch inte med tes so that oxal a eti a d can b c n ta tly ava l bl f the re t n One uch mechani m s th addi tion of arbon d ox d t pyruv c cid w th the oxid t n f reduced tr phosphopyrid ne nu leotide (TPNH) Th s ea t on which y elds m l ac d is catalyzed by th m l c zym O aloacet c a id c be y the ed from pho phoenolpyruvic a id a d CO in th pre n of inos ediph phat by a differe t nzyme A th r mp tant mea of thesis g f u -ca bon d carboxylic cid a seq ence of actu n n which isocitric cid s split to u n c and gly xyl c a id nd th l tte c mp u d a ts with ac tyl C A t y eld mal a d A a e eque c of the a ti n two m l ules of lo -carbon c d n be prod ed with the on mpt n of n m lec l f xalo- n d nd tw m lecul f cetyl CoA S e ADENOSINE DIPHOSPHATE (ADP) ADENOSINETRIPHOSPHATE (ATP) CELL (BIOLOGICAL) COENZYME CYTOCHROME DIPHOSPHOPYRIDINE NUCLEOTIDE (DPN) ENZYME PORPHYRIN TRIPHOSPHOPYRIDINE NUCLEOTIDE (TPN) [M D]

Kronig Penney model

An de ed e-dimen on l model of ry t l hich exh b t m y of the ba f atu es f the ectronic t u tu of e l ry tal Co der the pot t al ene gy V (x) f n elect ll t ated Fig 1 w th n nfin t equ e f pot t l w ll l d pth −V a d width arr nged with p i g b Th Sch od g r w equ t n an be r ad ly sol ed f s ch a arr ngeme t t gi e el ct o e gy a fu ti f w mbe

The e ergy b d th bt ned with a c rta n h of tt nt h wn F g 2. The Kr nig P ney mod l h b en xt ded t l d th f

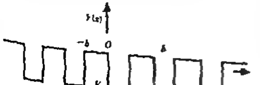


Fig 1 P m of gy as m d f th K g-P n- y mod l

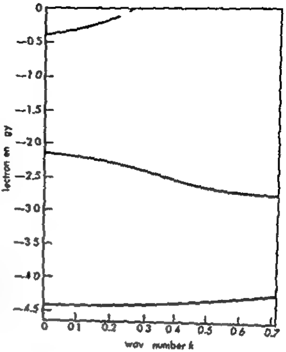


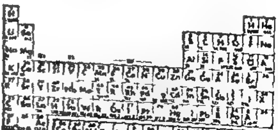
Fig E gy a f nct f w n mb k for th K g-P ey mod l

fe ts f mpur t atom A solut on an al be de ri ed from the D a equ t on See BAND THEORY OF SOLID QUANTUM THEORY NONRELATIVISTIC. [J C]

Bibl g phy R d L. kr ig and W G P n ney Qu ntum m cha cs f electrons in ry tal latti es P Roy So (London) A 130 499–513 1931 R D Wood and J Callaway Relat i stic K n g P ney Mod l ONP Tech Rept 5 19

Krypton

Ch m cal el ment numb 36 krypton Kr is a m mbe f the fam ly of obl [redacted] s gr up 0 f th period c tabl See INERT GASES



Uses Th pr n p l f r krypt n i filling lectric lamp and ele tr n c dev es of arious types Krypt tg n m ture ar w dely used to fill fl es ent l mp

Th h gh th m le l w ght of th t g s u ed t fill t ng t n filam t l mp bulbs th less th t nden y f th tung t n t evapo ate wh n

heated thus krypton is a better filling gas although more expensive than argon Two different uses are made of this advantage krypton filled lamps can be operated either at the ame brightness as those filled with argon in which ca e the life of the lamp is a good deal longer or at higher filament temperatures to give a brighter light at greater efficiency (more lumens per watt) but this reduces the life of the lamp somewhat An example of a use for the brighter lamp is in lide projectors and projectors for home movies

Krypton is also used to fill electric arc lamps An example is a new lamp the light from which will pierce fog for 1000 ft or more Lamps of this type are arranged in rows to mark airplane runways at night The lamps flash 40 times per minute each flash lasting only 17 μsec in order not to blind the pilots

Radioactive krypton 85 is relatively inexpensive and is finding a number of uses One is in leak testing of sealed containers Another is in the continuous measurements of the thicknes es of material such as sheets of metal and pla tics Another u e is in lamp which give off light for several years with no source of energy other than the radioactivity of the krypton in the e the invi ible radiation from the krypton activates a pho phor coated on the inner glass walls of the lamp and the phosphor gives off light continuously until the krypton has decayed to a low level of radioactivity Krypton 85 can be used to detect abnormal heart openings the introduction of this gas into the human body is practical because the krypton remains in the body for only a hort time working it way out via the blood stream and lung and i not fixed in the body

Occurrence The only commercial ource of stable krypton is the air although trace of krypton are found in minerals and meteorites Krypton constitute 1 14 parts per million (ppm) by volume of the earth s atmo phere and this krypton is almo t entirely a mixture of the following i otope none of which is radioactive 78 (0 35%) 80 (2 27%) 82 (11 56%) 83 (11 55%) 84 (56 90%) 86 (17 37%) The relative abundances of the i otope is gi en in parenthe es after the ma numl er Since ome radioactive krypton 85 is formed when atomic bomb are exploded the air now contain thi i otope and krypton recently eparated fr m air i very slightly radioacti e

A mixture of stal le and radioacti e i otope of krypton i produced in nuclear react r by the l w neutron fi i n of uranium

It i e timated that al out 2 × 10 % of th weight of the earth i krypton Krypton al oc ur out ide the earth the l e t e timat i that th r are al ut 51 at m of krypton for each 1 000 000 atom of the n in the ı d le unı er

Discovery Krypton wa di ov re l in Engl n l in 1898 by Sir William Ram ay and M W Tra ers they found it in the le v latile part of the inert gas mixture left after the oxygen and nitr gen ha l been remo ed chemically fr m a sample f air Th fact that a new element was pre ent was a certained by the di covery of new lines in the emi i n pectrum of the re idual ga

Properties Krypton is a colorle od rle and tasteless gas Table 1 gives ome phy ical properties of krypton

Krypton does not form chemical compound in the ordinary sense of the word although it f rm ome weakly bonded clathrate for example with water hydroquinone or phenol (see CLATHRATE COMPOUNDS) There is only one atom in each molecule of krypton

Production Stable kryp ton i produced in air eparation plant Air i liquefied and di tilled Krypton and xenon remain with the oxygen Th liquid oxygen is redistilled to concentrate the krypton and xenon from a few part per million to a few per cent The rare gases are then ad orl ed from the liquid oxygen onto ilica gel de orl ed eparated and purified Final purification i carrie l out by pa ing the krypton over hot titanium metal on which all except inert ga impuritie are remo ed

A mixture of tal le and radioacti e krypton i otopes i produced in nuclear reactor The only radioactive i otope in the mixture which ha a half life of over about 3 hour i Krypton 85 thi isotope ha a half life of al out 10 year Th i wh n krypton from a nuclear reactor has l een t red f r e eral day the only radi active i otope left i krypton 85 Tal le 2 give the appr ximate i otopic compo ition of the krypton thu produced The comp iti n of the krypt n mixture varie ome what with c ndition in the reactor A nu lear reactor come into wide u e for power pr l ı tion a large am unt of radi active kryp t n will l come available Since no cheap meth l of eparating the radi a tive fr m the table i top e of krypton i known th n i lear r a tor i not at pre ent a source f tal le krypton e en th ugh al ut 9 % of the krypt n produce l in it c n i t of stabl i otope

Analytical methods The principal m tern meth d f d t cting and quantitatively let rmining the krypt n ntent in ga e are ma spectr metry and ga chr matography Until these

Table 1 Physical properties of krypton

At mic n mbe	36
Atom w gl t (atmo pl krypt n only)	83 80
Melti g po t C	1
Bo l g p nt at 1 atm pres C	1 34
G s le ity t 0 C l l tm p es e g/l t r	3 t
Liq d l ty t its bo l ng po t g/ml	4
Sol l l ty i w t ml g p 1000 g w ler at 25 C l 1 tm p n	8 5

T ble 2 Isotopes in reactor produc d krypton

M	be	I t g f y l m S[illegible] l l	[illegible]
8 80 8		1 3	
83		13 14	
84		33	
8			(
86		16 0	

m thod ere devel ped it wa ec ary t s p rat krypt f m ther ■ es by lect e low t mp t d pt on on act ted ca b n i rd t d t rm ne h w m h krypt w s pre t a mixt ■ Th older method f detect ■ kryp t makes use f ts cha a t r tic m ion p trum btai ed by pa g gas mple th gh an lect d sch ge t b at low pre ■ and a lyzi g the light w th a p ctr mete S ATMOS PHERIC ■ SE PRODUCTION OF [C A C]

B bliog phy F P Cro Jr R e ga es ev ryd y e *J Ch m Ed* III 533-539 1941 R F Ki k d D F Othmer (ed) *E cycl ped a of Ch m cal Tech logy* 1 7 1951 F J M tzg T a es of (ra e g ses) f m t *I d E g Chem* 27 112 116 1935

Kudzu

A arm seaso pe e ial leg me with l ng p e d ing stem a d enl ged oot a d w th t ff b wn h r cov ring th y u g stem a d the trif l te l a es. K d g wn n well-dra ed o l n the south tern p rt f the U ted St tes It p d ces mod t y ld of good f g b t i ea ly k lled by ove grazi

Kudzu est bl hed by tr pl t t f 500-1000 pl t per Th tem of the pla t p e d g p dly d ti g t the d p o- d a f ll t d abo t 3 y The p i the dy t u f h y r grazing

K d d t bo d d ood

K d f the m t f l pl nt f p od g a bl k t of gr wth ev r ly e od d ea nd n t p dcut A f w w ll f rtil d pla t e t bl hed l g th b d f h d p t ted f m w ds w ll p d e d g d e n 3-5 y H we e gr wth ft ll gres t ea hey d th f u ful nd t l d ffi lt

B m g bo t 1938 ext pl t ng f kudzu we m d th S uthe t b t d l ha oc ed n 1948 S LEGUM E OR CES [P T]

Kumquat

M mbe f th g u *F tu ll* wh h o f th x g n ra in th gr up f t t f t Th kumqu t a b l eved t h g ted

F t l t f N g mi k mq t (F rt ll m g t) U H c M F I d C)

Chi and the M lay P t ila B t are n w w del gr wn in ll citru are f th wo ld There ar everal p cies the mo t omm n k e g *F m g rita* wh ch has o al haped f uit a d *F j p nica* wh ch ha r nd f it

Th k mq t ar hrub r m ll tree the r tems lea es fl wer nd f uit r mble *Cit u* k mq at b r umer u fl m t a g -colo ed f u t f m ll e ft n l th 1 in i d ame- t r ha ng 3-5 l t les fill d with n ac d pulp a d we t ed ble p lpy r d Th tree r am ng the m t c ld h dy f th tr fr t nd tav d rm t ev d r g p tra ted w rm pell in the wi t r mo th wh ch nables th m t w th t nd low temp at

Th kumquats with th r br ll t r ge-c l ed f t d d n e g ■ f liag ■ h ghly ornam n t l a d a m t fr q ■ tly gr wn fo th ea Sp ay f f li g a d f it e c mm ly u d f r de r tion p t ul ly i gift package of rd n ry tr f u t Th k mq at f t an be eate wh le w th t p li g d a e l o used in marm l d d p e rve nd c ded f u ts Th i ult the U ted Stat s a rel t ely sm ll cale S FRUIT (TREE) [F E C]

Kutnahorite

A c b t f c l m a d mang es C M (CO) K tn h t ne e f nd in na t r witho t me m gne m d ub titut g f m ■ es I t g t o f m n al sy the how ompl t l d luti b tw en al n a d K tn h it t somewhat l t d temp ra tu e

K tnah te h h g l (rh mbohed al) sym m try d the m t uct e d l mite It p k c l d h p fi gra ty of 3 It i f nd Czech l ak a Sw d a d t F nkl N w J r y S CARBO ATE I ERALS

B bl g phy J R Goldsmith and D L Graf [R I H] The y t m C O-M O CO l d l t n d d

composition relations *Geochim et Cosmochim Acta* 11 310–334 1957

Kyanite

A nesosilicate mineral composition Al_2SiO_5 crystallizing in the triclinic system Crystals are usually long and tabular and commonly occur in bladed aggregate There is one perfect cleavage the specific gravity is 3 56–3 66 The hardness of kyanite one of its interesting features is 5 (Mohs scale) parallel to the length of the crystals but 7 across the length

The luster is vitreous to pearly and the color is usually a shade of blue but may be white gray or green *See* SILICATE MINERALS

Kyanite is a polymorphic form of Al_2SiO_5 the other forms being andalusite and sillimanite These three minerals are found in aluminous metamorphic rocks each stable under different condition Kyanite is formed at low temperature and high pressure relative to andalusite and sillimanite The transitions from one mineral to another are so sluggish that they may coexist in the same rock. *See* ANDALUSITE SILLIMANITE

Kyanite is characteristically found in mica schists often associated with garnet staurolite and corundum Fine crystals some of gem quality are found at St Gothard Switzerland Kyanite has been mined in India and in the United States in Georgia and North Carolina for the manufacture of highly refractory porcelain [C S HC]

L Labradorite—Lytic reaction

Labradorite

A plag cl e feldspa w th a omposition ranging from $Ab_{50}An_{50}$ to $Ab_{30}An_{70}$ (Ab = $NaAlSi_3O_8$ and An = $CaAl_2Si_2O_8$). I the high temperature tate l b dorite h alb te-type structure In the co r e f cooling n tu al mater al d vel p pecul a structu l tate hi h whe i ve tigat d by x ay h s flecti n th t i dicate the beginn ng of an e sol ti n pr s s met me accompan ed by a b t f l r ou ly olored l ste (lab adorizing) See Feldspar Igneous rocks [F LA]

Labyrinthodontia

An import t gr p of f il amph bi ns de sce ded from c o s pteryg an fi hes a ce tral t ptiles and pr bably ant ced nt t part if not all the o he amph b an types The labyri th donts ranged i time f om Late Dev nia to Late T ia s c and i cl d d all the l rger nc ent amphib ans a d as a variety of sm ller types The labyr nth od nts w e chara teri ed by the apsido p d lo s rt bral c tra with di ti ct interce tra and pleu roc ntr of n ble c n tru t o Earlie t f l by rinth dont wer the Ichthy tegalia of the Upp r Devon they were succ eded by the Rha hitomi domina t in th C b n f s and Permia which t s ce ded n tu n by the T emat a ia and St eo pondyl n the Tri s c In th e f ur gro p cl s ed a T mn p ndyl the pl u c n tra we e small nd s m t m s ab e t l a d ed gr p the A th a au fo nd i th Ca bo f d P m a th ple o ents had e p ded mpl t g cl ded te the Embol meri nd f rm le ding to th S ym u amorph and th eptile S Am hibi fossils E tbolo meri Ich h ostegalia Rhachitomi Stereo spo dyli [A S]

Labyrinthulales

A little t d d gro p of m g m f un t in l t h ps They s e g lly gard d s l m m ld nd lo g w th the pla m d um f m g My g t l th p ud pl m d um f rm g A r les d th phyt p thoge Pl mod o- ph l they a t l ded i the phyl m Myxomy ph ta f th b t t th My et z d of the tool g Th r l ttle t ugge t cl e affin ty t a y ne f th g up nd gnm nt w th th m l g ly a m tt f o en n b a th v fit o th r k w gr up f pl nts or a mal All aqua c, a d m t a m e f rm that grow n in ssoci t w th m y typ of lg e d other marine pl nts Their ability to para it ze dia t ms has been clearly demon trated and they are gene ally regarded a the pathog ns resp n ible f r the o- alled wa ting di ea e that alm t ob- l terated the eelgra (*Zo t a m rina*) fr m t e hallow water along th Atl nt c eaboard be- tween 1931 and 1940 See Acrasiales Myceto- zoida

The egetat e cells of *L by nthul* the nl g nus pre ently ec g z d are typ cally f i sform n h pe nd mo e by a curi s glid ng m t on up n a netw k of slime t ack that they them l es pro- du Th netw rk f ana tomo ng path and mo ing ells was r ferred to a a net pla mod m by early invest gators and more th n any ther fea ture of the r de elopme tal cycle th unique tage cha act rizes the genus *Labyri thula* The egeta ti e cells are not amebo d i a t e n e alth ough they ha e been so reported and do in f ct show re markable pla ti ity as they glide past one another o mo e ar nd ina im te objects encou tered in their path They are not nourished by the engulf ment f bacteria or other particulate food but by the uptake of nutrients in solution or those that th y s lubilize by extracellular enzymes as when growing par itic lly upon d atoms or other liv ell Reproducti n occ rs by transver e or longi tud nal d i n f the f ifo m cell following a pri r m t ti d i n of the nucle s A flagellate tag has bee obs rved upon rare o ca on but its gn fi ance in the l fe cy le rema s b c r

Spec es of *L byn thula* an be readily culti ated n the l borat y up n a s lt agar medium c n t ng of fresh s a w ter en h d w th 10% blood ert m as epo ted by S W Wat n and E. J O d l [K B R]

B bl g phy S W W ts n and E J Ordal T chn q e f the i lat n f *Laby thula* a d *Thr u tochytrium* in p e c lt re *J B cteri l* 73 589-590 1957

Laccolith

A geologi nam f body f gneou rock in t ud d i t d me tary r ck su h a w y that the e ly ng trata ha e bee ot bly l fted by the f c f ntru I th m st simple ex mpl the l c l th e c la r al pla the ubj nt ed ment ry k nd the floo of the la co- l th r n ly h r z nt l d the oof i d me- haped w th th sed m ntary ro ks a h g o er the d me Type xampl in th H ry Mounta n Ut h (de c b d by G K Gilbert in 1877) a d m ny upp d ex mple sub equ ntly d cribed

in the western United States have been shown by more detailed work to be much more complex than originally described. See PLUTON. [J.A.N.]

Lacquer

A surface coating the vehicle of which contains a substantial quantity of a cellulose derivative. This derivative is most commonly nitrocellulose, but may be a cellulose ester, such as cellulose acetate or cellulose butyrate, or a cellulose ether, such as ethyl cellulose. The term is sometimes used for other coatings which have properties and uses similar to those of lacquers, particularly clear metallic coatings. Originally, lacquers were coatings produced by the use of the juice of a tree of the sumac family, but these materials, often called Oriental or Chinese lacquers, are not widely used today.

Lacquers are made by dissolving nitrocellulose and other modifying materials in a solvent and pigmenting if desired. They dry by evaporation of the solvent. Because solvents with very high volatility may be used, extremely fast drying times may be obtained, and lacquers are usually applied by spray. The drying time may be extended to allow brushing, but brushing lacquers are not commonly used.

Nitrocellulose is not soluble in conventional paint thinners, so that a mixture of solvents, usually containing esters (ethyl acetate), aromatic hydrocarbons (toluene), and petroleum thinners, are used. Alcohols and other solvents may be present. The solvents must be chosen carefully for the combination of solvency and evaporation rate required.

Nitrocellulose is very hard; its flexibility is modified by the addition of plasticizers. These may be *vegetable oils, such as castor or linseed, which have* been modified to be compatible with nitrocellulose, or chemical compounds, such as dibutyl phthalate or tricresyl phosphate. Numerous other materials are also used for this purpose. The adhesion of lacquers can be improved by the addition of other resins, and these also may reduce the cost by allowing the use of less expensive solvents or, alternatively, allowing the application of heavier films.

Historically, *the development of lacquers came* in the early 1920s, when ample supplies of relatively inexpensive chemical solvents became available after World War I. This coincided with the great increase in the production of automobiles and the demand for a fast-drying, weather-resistant finish which could be used to replace the previously used enamel, which required long drying periods. Lacquers still constitute the finish used on about one-half *the automobiles produced* in the United States and furnish a substantial portion of the coatings for furniture and other factory-finished items.

Lacquers using other cellulose derivatives are much less common. Cellulose acetate, acetate butyrate, and butyrate have certain specific uses, particularly for clear coatings where good weather resistance is required. Ethyl cellulose gives films *of extreme flexibility, but such coatings* are too soft for many uses. See PAINT; SOLVENT; SURFACE COATING. [F.D.]

Lacrimal gland

A tubuloalveolar or acinous skin gland also known as the tear gland. The lacrimal glands develop from the skin epithelium which folds inward over the developing eye. Two types occur among the vertebrates, the lacrimal proper and the Harderian. The eye glands are first found in the amphibians, associated with the inside of the lower eyelid. In urodele amphibians the eye gland extends along the inner aspect of the lower eyelid. In *Salamandra* it becomes divisible into an anterior Harderian gland associated with lower eyelid structures and a posterior lacrimal gland below the upper eyelid. In frogs and toads only the Harderian gland is present and is associated with the nictitating membrane or third eyelid which develops in relation to the lower lid.

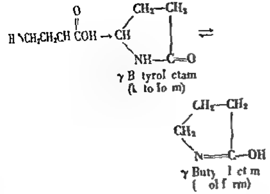
The eye glands drain into the nasal cavity by means of the lacrimal duct. In higher vertebrates, with the exception of snakes, certain lizards, and geckos, Harderian and lacrimal glands are present. In the higher vertebrates the Harderian gland functions *in relation to the third eyelid* or nictitating membrane, and the lacrimal gland become located dorsally above the eyeball near the outer angle of the palpebral fissure. In aquatic mammals, such as seals, whales, and sea cows, the Harderian gland is the more prominent of the two sets of eye glands and it secretes a sebaceous or oily substance. In land mammals the lacrimal gland proper is highly developed as a complex tubulo-*alveolar structure with several ducts* which pour their copious fluid into the outer, upper part of the conjunctival sac or cavity. The tear *substance* washes across the eyeball to the inner palpebral fissure or commissure. Eventually it passes through two small openings, one on the margin of each lid, into the lacrimal duct. The latter converge to form the lacrimal sac, from which the nasolacrimal duct leads into the nasal passageway. Tears contain *a considerable quantity of the common salt,* sodium chloride. See EPITHELIUM; EYE; EYE DISORDERS; GLAND. [O.E.L.]

Lactam and lactim

Lactams are internal (cyclic) amides formed by heating γ- and δ-amino acids; structurally they are nitrogen analogs of the corresponding γ- and δ-lactones. Thus γ-aminobutyric acid readily *forms γ-butyrolactam,* commonly known as pyrrolidone.

The formulas show lactims to be tautomeric enol forms of lactams with which they form an equilibrium, where the lactam nitrogen carries a free hydrogen.

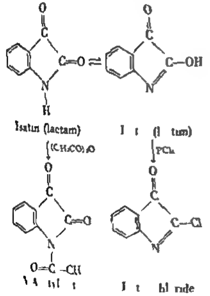
Pyrrolidone has weakly acidic and basic properties, forming a hydrochloride and a sodium salt. Alkylation of the latter gives N-alkyl pyrrolidones.



With a etyl ne *N* inylpyrrol d e f m poly me g t p lyv ylpy r lid ne the latt r i u ed t aer sol p y fo hai tt g

Comm r al p d tt l pyrr l done ut l e e ther tr atm nt f γ b ty la m e w th mmon the p rt l r d ct n of su ci m de P p r d ne (δ l l ct m) i m d f om δ al ol ct e and mm Sm ller r g (β l t ms) and la ge (d h ghe) m t be made b nd re t method h dd ti n of kete es t im es f β l ct m d g xpa i n a B ckma n re rr ng m t f cycl k t xime fo a d higher l t ms.

Th ta t me qu l br m x t g between la t m d l t m t ctu e i w ll e mpl fied i at n n dat n p od t of i dig



Th t a th l i m t w th t c an h d d t f m \ tyl at w th ph ph u pe i hl d t e t a th l t m g g t hl d

Alth gh y d δ m c d e nt i themsel es th r p d g la t m sh w p o ed t h t p t ty *S e* A INO CID L CTI A D LACT NE [E B R]

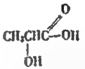
Lactase

An enzyme found n mammal h ey bee larv a d me plant It i a β gala t ida e wl ch l y d l z la t e t g l ct e and gl In mam mals la t e app r in the i te ti al s cr ti n that i fr m the i testi al villi a d e erts its effect o la t e in chyme *See* E ZYME GLUCOSE.

[D N L]

Lactate

A alt r e ter f la tic cid



in wh ch the ac d hydrogen has b en replaced l y m tal o a orga ic rad cal Alkali metal alt ar w ter l ble th rs ar in l ble Ma y alt h pr ct al applicat n f r ampl a l lood gul nt n calc m therapy (alci m) a a tip p r t (lum um) in tr atment f a e m a (i n) and a pl t ci r (d m) Lower m lec lar w ight t s ar water l il l E te u d a ol ents f lacquer cell l e c tate and ell l e n trat *S e* CARBOXYLIC ACID ESTER LACTIC ACID SOLVENT [E H H]

Lactation

The f n tio al a t tv f th m mm ry gla d whi h the e eti n f m lk

Soo aft r birth the you g b g n p iod nurs r m lk rem l A ery mport nt mechani m n l g both the ervou and docr ne y tem m i to pl y Th a t f n r i g s nd nerve m pul t th b and p te i p t itary whi h th d h rg f oxyto n i t the l lood Th s h rm e fl t th m mmary glands cau g th o t a t o f m ep thel al c ll whi h urr nd e h l l f i g th m lk f m the l me f the l ol m the d t f r rem al by the n l ff th m th r i d ti bed t th time f r g hormo e dren l n is d charg d f m the adr l gla d If ad nal aches the m mma y gland bef yt c s di charg d n p e t th e nt a t n of th myo p th l m a d m lk m al d s n t t ke pl e Th n sing m th m t b nt ted a d fre of t e r citeme t

Milk production The fi t milk c l trum s et d b f re pa tur ti t p t lly t h in g mm gl bul wh ch e t n imm ne bodi Th d gest t t f th n wb rn b b th s p t nta t nt the blo d th nf a tempo ry mm ity t mm n d a e W th the regu l r m l of m lk th am nt f m lk s ret d n r fo a per d of t me then gradu lly d l e u t l th mal a d i dry up l d ry a m l h the w p gnan y i duced b t th t th d y f th l ctati n p i d La

tation and pregnancy with additional growth of the mammary glands occurs so that a second lactation period is initiated at yearly intervals. The total yield of milk increases each year until about the seventh or eighth year, then declines with old age.

Control of secretion. The secretion of milk is under hormonal control. At the time milk is removed by the mediation of oxytocin, the nursing stimulus also causes a discharge of lactogenic hormone into the blood which stimulates milk manufacture during the interval between nursings. Without this hormone the cells cease to secrete milk. However, there are a number of other hormones which influence the intensity of secretion. Of these the growth hormone of the pituitary gland and thyroxin from the thyroid gland are most important. The effectiveness of these hormones can be shown by their administration during the declining phase of lactation. When thyroxin is injected or thyroprotein is fed to dairy cattle at this time, there usually follows an increase in the yield of milk for a period. On the other hand, if the thyroid gland is removed, lactation is reduced up to 40%. An optimal level of thyroxin secretion is essential for optimal milk secretion. The growth hormone which regulates body growth also plays an important role in regulating milk secretion. See MAMMARY GLAND; see also ADRENAL GLAND; PITUITARY GLAND; THYROID GLAND. [C.W.T.]

Lactic acid

A slightly hygroscopic syrup with a specific gravity of 1.294 at 25 C. The acid, also known as α-hydroxypropionic acid, contains one asymmetric carbon atom and exists as two optically active isomers that can be converted by an enzyme, racemase, into the racemic mixture (see OPTICAL ACTIVITY; RACEMIZATION). L(+) Lactic acid, also called sarcolactic and paralactic acid, is metabolized by animals, whereas D(−) lactic acid is not. The lactic acid of commerce is the racemic mixture, commonly known as *i*-lactic acid (optically inactive). Annually 5,000,000 lb is produced for use in pharmaceutical preparations, in the textile and leather industry, in the production of inks, solvents, lacquers, and plastics, and as a food preservative.

Lactic acid may be prepared chemically although industrial production is by fermentation.

Fermentation. Industrial production of lactic acid is accomplished by fermentation of refined glucose, hydrolyzed starch, whey, and molasses. The more refined substrates are used for production of the higher grades to reduce purification costs. Sulfite waste liquor, juice of culled citrus fruits, enzymatically hydrolyzed potatoes and acid-hydrolyzed wood, mill sawdust, straw, corncobs, extracted beet slices, and Jerusalem artichokes have also been proposed as substrates.

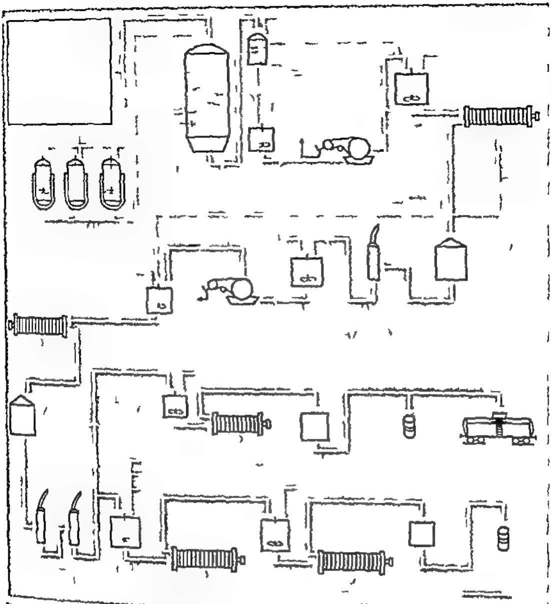
Bacteria suitable for commercial production of lactic acid may be isolated from souring foods, grains, malt sprouts, or soil. These organisms have complex nutritional requirements. For example, *Lactobacillus delbrueckii* requires 14 amino acids and 4 vitamins and is stimulated by a number of other substances. These growth factors can be provided by adding small amounts of malt sprouts, corn steep liquor, distillers grains or solubles, koji, rice bran, peanut oil cake, soybean cake, undenatured milk, or extracts of liver and yeast. Maintenance of the culture requires frequent transfers in media of low sugar content such as 5% corn mash.

In one commercial process *Lactobacillus delbrueckii* is transferred serially from test tube to flasks, to seed tanks, and finally to the wooden or stainless steel fermentor, maintaining an inoculum level of 10%. Each transfer is made after 16–20 hours of growth at 49 C, which is assiduously controlled. The medium, consisting of 15% glucose, 0.4% malt sprouts, 0.25% diammonium phosphate, and 10% calcium carbonate, is not sterilized. The industry relies on cleanliness, the high temperature, and low pH to restrict contaminants. Butyric bacteria are the most troublesome, particularly as they produce volatile acids in addition to a racemase. Although the batch process is usually employed, *continuous processes have been devised.* Corrosion is a major problem.

The fermentation requires four to six days when the concentration of sugar falls to 0.1% or less and the yield reaches 90–95%. Small changes in pH adversely affect the fermentation and automatic control is advantageous. The optimum pH of 5.6–5.8 is maintained by adding sufficient calcium carbonate initially or intermittently as required. Although not used industrially, the submerged cultu

Table 1 Characteristics of lactic acid organisms

Organism	Morphology	Substrates	Optimum temperature	Acid produced
Lactobacillus bulgaricus	Rod	Lactose, whey	4[illegible]0 C	Racemic
Lactobacillus delbrueckii	Rod	Glucose, molasses	4[illegible]0 C	L(+)
Lactobacillus brevis	Rod	Pentoses, hydrolyzed wood	30 C	Racemic
Lactobacillus plantarum	Rod	Pentose, sulfite liquor	30 C	Racemic
Streptococcus lactis	Coccus	Lactose, whey	3[illegible] C	L(+)
Bacillus coagulans	Rod, forms spores	Glucose, lactose	4[illegible]0 C	L(+)
Rhizopus oryzae	Mold	Glucose, starch	30 C	L(+)



Flo sh t f th p od ct f l ct d

u ol RA pus y e t med c tai g 13% gl ose g es 75% y eld f la t a d n 35 ho rs Thi f rmentat h th d ad ntage of l we y ld nd q ng a ept c d ti but the ad nt g of p od g l ct a d a l r b th Reco ery f la t c d f m f rm nt d l q or r th d ffi ult bec e f th l w ap r p ur f lactic d nd t t d cy t f rm a hydr de d derg ll est r fic t wh n heat d and co t ed bo 20% d l b a t olu bil ty m l r t w t Th imp rta t t m ts e p ot r f me ted s g n gani lt and l ed m te i l The u ual p t ce s t co g l t the p t d mplet ly e t l z th lactic d by he t g t 90 C w th l m Th sol ble m tt is rem ed by filt t n f ed m t i l a d l bl p t by t e t m nt th ha oal Th c l m l t te th

eithe c nc t at d a d p y d ied o c l d and llowed t cry tall La t c acid pr pared by treat g a olut n of calci m lactat with sulfur ac d nd filt ng ff th n l ble c l um ulfat The cid s th n r p t dly bleach d until the de r d pu ity atta ed S m o g n impurit s in l ct ac d c be de tr yed by tr atme t w th ox d z g a t u h hyp hlorit n tr c ac d

Alt rnat e methods p op s d f pu ify g l ct d i l d (1) team d till t on nder cuum (2) cry t ll zati n as th c o line lt (3) e tra t n f th la t c c d with nitro- pa affin isop opyl ether o myl alcoh l d (4) con e s n t n t r Th l tt r proce s has be c s f lly ppl d to the re y of methyl l t te f om f m ted p tato m he

Chemical production La t c d may be p e p d hem lly by (1) r acti g l hyd ox d

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Lactobac llus plantarum	Rod	Pentoses ulf t l qu r	30 C	Racemi
Streptococcus lactis	Coccus	La tose whey	3 C	L(+)
Bacillus coag lans	Rod f r s pores	Gl cose l tose	0 C	L(+)
Rhi opus ory ae	M ld	Glucose star h	30 C	L(+)

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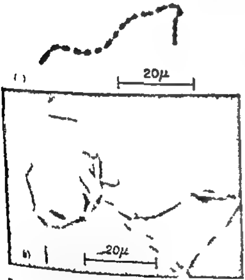

Fg 1 Morph logy f th tw t b f th L ct b cillaceae ph ograph ( ) St pt f l tribe S p ococ (b) L ct b ll b t b L ctobacilleo

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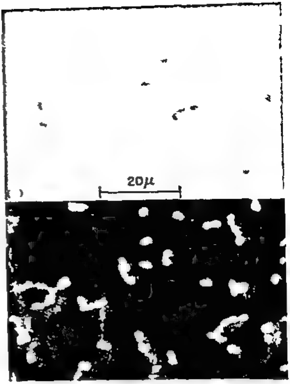

Fg 2 Ph t m g ph f L t m f d t b St pt ( ) E p l t d c ll (b) Ch d ■ d d gl ■

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Fg 3 Ph t m g ph f t t d d p d ll

Table 2 Grades of lactic acid

	Tech cal	E I I I	Pl t c	USP
Tot l d ty	41%	50%	50%	85%
Volat l d	1 %	1– %	1–2%	–3%
A h	0 6–0 7%	0 1–0 5%	0 00 –0 01%	0 05–0 1%
C boni able m tt	Present	P ent	Non	Non
Colo	B own	Pal y llow	Col les	C l less

with bromopropionic acid (2) oxidizing 1 2 pro pane diol with permanganate (3) deaminating alanine with nitrous acid (4) reducing pyruvic acid (5) combining acetaldehyde with carbon mon oxide at 200 C and 900 atm pressure (6) hydro lyzing acetaldehyde cyanohydrin and (7) degrad ing sugars with alkali These methods produce ra cemic lactic acid and being more expensive than the fermentation proce s are not widely employed D(−) Lactic acid may be prepared from methyl α D 6 deoxymannopyranoside and L(−) lactic acid from methyl α L 5 deoxyarabinofurano ide by oxi dation with periodic acid and bromine in aqueous olution

Production of lactic acid by alkaline degradation of sugars according to the following equation is the subject of numerous patents

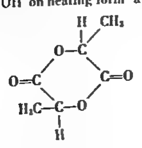
$$C_1 H \ O_1 + 2CaO \rightarrow$$
$$2Ca(—O—CO—CHOH—CH_3) + H_2O$$

In practice however the sugars undergo many other kinds of rearrangements fragmentation and oxidation The yield of lactate is therefore of the order of 50% of the theoretical In alkaline solu tions sugars undergo rearrangement fragmenta tion and oxidation to various acids The yield of lactic acid depend on such factors as structure of the sugar concentration and type of alkali and temperature Sucro i mo t efficiently degraded and aldonic acids are superior to aldo es When mola i diluted to 18% sugar and treated with 13% calcium oxide for 2 hours at 230–235 C the yield of lactic acid is about 40–50% *See* CARBOXYLIC ACID [F J S]

Bibliography R Montgomery *The Chemical Production of Lactic Acid from Sugars* Sugar Re earch Foundation Sci Rept Ser 11 1949 S C Pre cott and C C Dunn *Industrial Microbiology* 3d ed 1959 L A Underkofler and R J Hickey (ed) *Industrial Fermentations* 1954

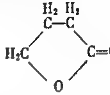
Lactide and lactone

Lactides are cyclic intermolecular d uble esters formed from α hydroxy acids Thus lactic acid CH CHOHCOOH on heating form a lactide



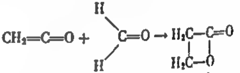
Glycollic acid HOCH COOH behaves anal gously In each ca a bimolecular interaction oc curs forming the strain free 6-membered n g Most lactides are relatively low melting solid and are easily hydrolyzed by ba e to form alts of the parent acid for example odium lactate

Lactones are internal cyclic mono e ters formed by γ or δ hydroxy acids pontaneou ly thus γ hydroxybutyric acid HOCH CH CH COOH forms γ butyrolactone



Other lactones of maller or greater ring ize are prepared specially

The γ and δ lactones are commonly prepared by either hydroly or di tillation of γ or δ halo acids by treatment of un aturated acid with aq e ous hydrobromic or sulfuric acid or by partial re duction of cyclic acid anhydride β Lactones re sult from the reaction of ketene with aldehydes or ketones



β Propiolactone

Large ring lactones can be made by oxidati n o cyclic ketones with Caro s acid thus cyclohexa none yields caprolactone

The lower lactones are neutral liquids that reac with ba es (alkalie ammonia and amines) to gi open chain derivatives of the parent hydroxy acids Very large-ring (macrocyclic) lactone for exam ple 15 or 16 carbon have pronounced mu k od r (perfumes)

Unsaturated lactones (butenolides) are widel distributed for example the angelica lact nes penicillic acid and protoanemonine (mold metabo lite) coumarin (tonka bean) and dicoumaro (spoiled weet clover) ed medicinally a a hem orrhaging or anticl tting agent in coronary thr m l o i *See* ESTER [E B R

Lactobacillaceae

A family of bacteria of the order Eubacteriales A th ugh they are primarily sapr phytic a few spe cie are path genic The lacteria are g nerall known a ugar fermenters producing lactic ac a a maj r produ t They are f und in f rmentin f d produ t in the m uth in the inte tinal trac and in l ly le t n Th saprophyte u ually ar n nm til and sh ow neither reducti n f nitrate gelatin liquefaction catala e producti n n r su fa e gr wth in li quid media The speci are m croaer ph ilic or anaerob ic inacti e t ward pr te ources l ut f tidi u m th ei req irement Som strain l ave l ec m val l gical a

bec ▪ of th e ct g t ti nal req ▪ ts S BOASSAY VITA IIN

Th f mily d ded m ph l g ally into a tribe f ph l l ghtly elo g ted c c f rms, Streptococce a d t ibe f od f m La tob llcae (F g 1)

M ph l ov m s th rel ble g de t cl s fi ti b t t ble data are s anty Phy lo cal h a t th f d p bl ▪ th gh some t m ts prefe n t t u h har ct f r d ff tust b y d the spe ▪ lev l

Streptococceae Th t b Str pt ▪ d vided to fi g a ba d pon m ph l l and phy l gi l har t ▪ Th p of f f these D pl o us St pt c L o ost c a d P pt st pt ccus in l d typ l ph c l coc f rm h h d ide e pl a d u lly oc u i pa s sh rt h (F g 2) The fifth g P d c l de p ▪ wh h ft n oc tet d gro p n t t di i n t o pl (Fig 3)

F u of th ge bt th r ▪ ey by f me t ti n f c b hydr t l t d mp d Th l d th pe es f th g a D pl o d St pt us wh h p od d t t

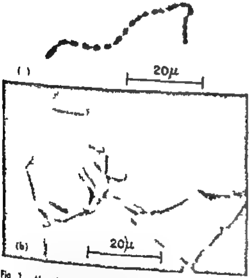
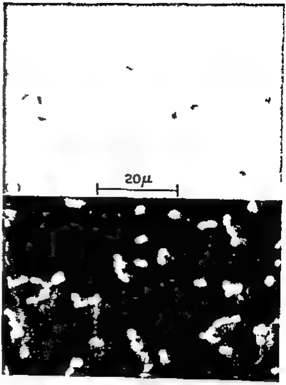


Fig 1 M rph logy f th tw t b f th Lact b lla ph t m og ph (a) St pt f t tribe S pt (b) L ct b ll ▪ tr b L tob ll

t l t a d p f th g P d wh h p od e em m xtu f l t d d L u t p wh h p d d abl m unt f a bo d d thyl l h l d t a id dd t t l t t ry l t c d Spec es f the fifth g P pt t pt c us a b t l e p t -dec mp t p od t ll boh d at d p d a d th than l t a d a l



Fg 2 Ph t m g ph f L st m t d t b St pt (a) E p l t d ll (b) Ch d p d d gl ll

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Th ge L t l des th h t f me t t p e so t d w th f d They w ▪

Fg 3 Ph t m g ph f t t d d pa d ll f P d

fir t ob erved in the slime ma ses of sugar factories They convert glucose to levo lactic acid alcohol carbon dioxide and acetic acid and in addition partially convert fructose to mannitol and sucro e to dextran

The species of the genus *Pediococcus* fir t isolated as contaminants in beer have been observed in other fermenting foods They include the highe t acid producing sp cies in the tribe

The species of the genus *Peptostreptococcus* are usually anaerobic sociated with septic and gangrenou conditions or found in the respiratory tract and may be pathogenic The species differ physiologically from those in the other genera in their growth on protein decomposition products as well as on organic acids and carbohydrate with production of carbon dioxide hydrogen hydrogen sulfide and various acids in addition to lactic acid

Lactobacilleae The tribe Lactobacilleae is divided into five genera ba ed upon morphological and physiological characters

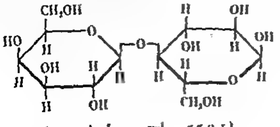
The species of the genus *Lactobacillus* include the high acid producing bacteria associated with fermenting foods and the intestinal tract They include two general groups The homofermentative species like tho of the genera *Streptococcus* and *Pediococcus* among the cocci produce lactic acid as a major fermentation end product The heterofermentative species are comparable to tho e of the genus of cocci *Leuconostoc* in their growth end products

The species of the g nera *Eubacterium Catenobacterium* and *Cillobacterium* are low acid producing bacteria from the inte tinal tract and lesions and are comparabl with pecies of *Peptostreptococcus* among the cocci In addition to lactic acid formic acetic propionic butyric and other acids are formed during fermentation Some of the e may e pr tein degradation products They are di ided into the four genera on the ba i of morphological characters motility and cell branching The phy iology of these strict anaerobe has not been mpletely elucidated and further work may how that s m of the e species hould be placed in genera of other familie See EUBACTERIALES [C S P]

Lactose

Milk sugar or 4 O β D galactopyrano yl D glucose This re luc ng di a charide i f rune l as the α D anomer the melting point (mp) is 20 C and the optical acti ity i $[\alpha]_D^{20}$ +85 0 → +52 6 Crystallization at high r temperatures (above 93 5 C) gi the β D anomer mp 252 C and $[\alpha]_D^{20}$ +35 → +55 4 Lactose is found in the milk of mammals to the extent of approximately 2-8% It is usually prepared from whey which is obtained as a by product in the manufacture of chee e Upon concentration of the he crystalline lactose is deposited Lacto e is not fermentable by ordinary baker s yeast In the ourn of milk *Lactoba illus acidophilus* and certain oth r microorganisms bring al out lactic acid fermentat by transforming the lacto e of the milk into lact c ac d $CH_3CHOHCOOH$ See CHEESE MILK OPTICAL ACTIVITY

Chemical evidence shows that the glyco idic linkage involves the carbon atom 1 of the D-galactose and carbon 4 of D glucose Enzymatic studies indicate that the galacto idic linkage has the β configuration See OLIGOSACCHARIDE [W.Z.H]



La tose (α l rm rel g g o I)

Lagomorpha

An order of mammals including the pika rabbi and hares These were long regarded a rodents usually under the subordinal name Dupli identata but mcdern tudies how that lagom rph and rodents are only remotely related if at all Fo il remains of lagomorphs are al undant from the Oli ocene on but are almost unknown in the early Tertiary when the major radiati n of the tock wa taking place The hares and rabbits w r alread distinct from the pikas when they fir t appeared in the fos il record

The living lagomorphs are di tingui hed by having four inci ors in each jaw in tead of t o a in rodents The central pair i enlarged and chi el like the lateral pair reduced to mall p g lying behind the central pair Numerous other features in the dentition keleton and mu culature and serological te t empha ize the di tinctne s f the lagomorphs from the rodent The or ler i di ided into thre families The Eurymylidae containing a single known genus *Eurymyl s* fr m the Paleocene of Mongolia lack the second pair of incisor The Ochotonidae the pika or rock ral l it are small hort eared nonl aping form m re primi ti e than true ral l it The Le ri lae are l g eared leaping animal wit l ngat l l in l leg In the ral l it le pecialized tl an tl e hare th young ar l rn nake l and h lp le Numer u d me tic ariettie ex eed d in numl er only l y th vari tie of the d m ti log ha l een le el ped In the hare typ ifie l l y the ar tic hare an l the jack ral l it the young are well l aired and ha e their ey p n at l irtl See EUTHERIA LAGOMORPHA FO IL [D D D]

Lagomorpha fossils

The lagom rph ar l if l int th famil the ral l it an l lar (Le r la t th pika (O l t nidae) an l the primiti g nera E rym l an l M molagu (Eurymyl la l) c mpr ed with th r or ler f mammal th re i little mor pl l gi al li er ity in th Lag m rpha

l g m rpl m y be re gni l l enam le t r g t the p t r r a l f th r l rp n t

f ramen ak masset nd tempo al m le fine fenestratio s l teral rf ce of ma ill ry and som times other bo es ch ek teeth w th ro ts in arl ge a, becom o tless nd p ores i ly h gh c ed l t f rms ba ic d ntal f rm l

i rs $\frac{2}{1}\left(\frac{3}{1}\right.$ ewly h p kas$\left.\right)$ can n s $\frac{0}{0}$ p e

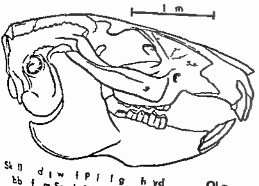
lars $\frac{3}{2}$ m lars $\frac{3}{3}$ *See* DENTITION

Th olde t k lag morph l ke mamm l *E y mylus* fr m the l te P leocene of M g l has 1 s d t th t o gly ugg t e of an ce t l l m ph b t al po ■ g haract that m ht be a ribed t n ect e t an ea ly rod t l t m diate f rm between *Eu ymyl s* and th e rl t g ther fam l s r n t kn wn P ka fi t app the l te Ol g e f Eu p d A h th ee ge e a k ow a d t n t th p e e t The d is al o p s e t i the M ene f Af App ntly p k a hed N rth Amer a the Pliocе e v N rth P fi d p l ro t Pikas pp ar ir the f l re d ■ po h lat than th l p d alth gh pik ■ p m t m ph l g cally

Lep r d ■ good f ssil ec d M t of th ge the N w World th gh th w m d p l int th Old W ld The m y l t ry t nd h b en f m m lle c mp g l po id t rd l g k d w th n al d sal t l h b t Th refle t d the n ly h rizo t l p tu e f th sk ll n lat t th ert b l l mn f e ly f m a d a m e le ted pos t w th th fac l eg b t d w ard l t f rm Th tre d al d pl yed th l g t of l ml d fo t b es w th g t r t t f l t ral m eme t

Th ubf m ly P l l g e f the l t F e th gh l t Ol g ne th p im d l stock f th Lep d The g a *Sh m l g G b l s d D m t l g* f m Eur d *Myto l s* f m N th Am m y h b l t the hypoth t l l g m ph th t mu t ha ■ e e to both the O h t n d d th Lep l

A h l ld t f th Ar h eola e l ed f m *P l l* i th l t Ol g ce ly M oc M t f th l t g n w n N rth Am a b t o g n *(Pl l gus)* ■ h d



Sk ll d i w f P l f g h yd Ol g bb f m So h D k t (Aft A E W d 1940)

the Old W rld d ring the Pl oce ■ The arcl ae ol g nes became tin t in the Plei t ene

The bfamily Lep rin ■ incl des the li ■ h res r bbit and s eral e tinct gener It is n t known wheth this s bfam ly ev l ed dire tly f om the P laeol g nae ■ f om th Archaeolag nae

[R A S T]

Lagrange s equations

Equat on of m ti of a mecha l sy tem f r whi h a cl cal (n q a tum mecha i al) de cript n uitable a d which relate the kinet c e gy of the ystem to the general ed coordin te the gene l d force a d the time If th ■ figu t n of the yst m pecified by gi i g th al ■ of f i depe d t quantitie q q_f th re are f such e juati n f m t

I th r ual form thes equ tions are equiva lent t Newton nd law f mot n a d a e d ff e t al equat ons of the econd order fo the q as f n t n f th t me t

Derivation Let th sy t m ■ f N particle The m es f the p ticles are m and th carte si coord ate are x ($\rho = 1$ 2 N $i = 1$ 2 3) Th rt c d n tes are xp e it l f t f f ($\leq 3N$) g n ral zed coord tes q q_f betwee wh h ther a no n t ai ts Th t me d n t ppear he e if the c n t t ar fixed (as will be umed)

$$x = f(q_1 \quad q_f) \tag{1}$$

The de t ng t m d ff tiat n by dot

$$x = \sum^{f} \frac{\partial x}{\partial q} q_i \tag{}$$

Th cart n el ty omp nent are lin func t s of th ge e l d vel ti q

L t δq epre t sm ll d pl em t of th y tem It ut m t lly on st nt with the con t ts I thi d pl cemе t th f c f n t t d w k their nly act is t p e t m t t y to th c t nt they h e n mp n t i th d re ti of a d pla em t c i t t w th th n tr t If W s th w k d n d g th d pl me t t i do e nt rely by the te ally ppl d f ces

$$W = \sum F \quad \delta x = \sum m_\rho x \quad \delta \tag{3}$$

E h term n the um (3) m y r ce cont ibut o f m f of n tr t b t th y c l wh n th mmat m d Fr m Eq (1)

$$\delta \quad = \sum \frac{\partial x}{\partial q} \delta q \tag{4}$$

th t

$$\frac{\partial x}{\partial q} = \frac{\partial}{\partial q} \tag{5}$$

It is readily verified that

$$W = \sum_j \left[\frac{d}{dt}\frac{\partial}{\partial \dot{q}_j}\left(\frac{1}{2}m_p\dot{x}_p^{\,2}\right) - \frac{\partial}{\partial q_j}\left(\frac{1}{2}m_p\dot{x}_p^{\,2}\right)\right]\delta q_j \tag{6}$$

The quantity in the brackets is thus for each j the noncartesian analog of the cartesian $m\ddot{x}$.

The only quantity which appears differentiated in Eq. (6) is the total kinetic energy T of the system. This is easily calculated in generalized coordinates because the connection between the cartesian velocities and the generalized velocities is linear and homogeneous. Usually the kinetic energy can be written by inspection without using Eq. (2) explicitly. Thus

$$W = \sum_j \left(\frac{d}{dt}\frac{\partial T}{\partial \dot{q}_j} - \frac{\partial T}{\partial q_j}\right)\delta q_j \tag{7}$$

Transforming the right-hand side of Newton's equation is simpler. Write

$$W = \sum F_p \,\delta x_p = \sum_j Q_j\,\delta q_j \tag{8}$$

where

$$Q_j = \sum F_p \frac{\partial x_p}{\partial q_j} \tag{9}$$

is the jth component of the generalized force. By the preceding argument Q_j depends only on the externally applied forces, the forces of constraint necessarily cancelling in the summation.

The displacement δq_j was entirely arbitrary. Thus it follows from equating expressions (7) and (8) for W that

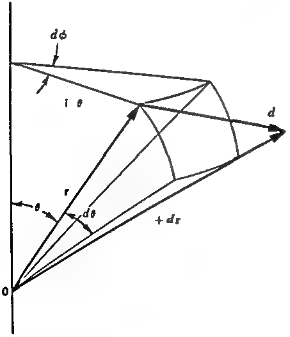


Fig. 1. The vector dr is decomposed into three orthogonal vectors of magnitudes $r\sin\theta\, d\phi$, $r\, d\theta$, and dr, respectively. ... θ and ϕ being spherical coordinates.

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{q}_j} - \frac{\partial T}{\partial q_j} = Q_j \tag{10}$$

These are Lagrange's equations of motion. They are valid also when moving constraints are present. See CONSTRAINT.

Examples. Use of this form of Lagrange's equations is shown in the two following examples.

Particle in central force field. Here the force acting on a particle acts always through a fixed point. Choose this point as origin of a spherical coordinate system with coordinates r, θ, ϕ (Fig. 1). Only radial displacements involve work, so only Q_r differs from zero.

$$Q_\theta = Q_\phi = 0$$

The kinetic energy is given by inspection of Fig. 1 to be

$$T = \frac{m}{2}(\dot{r}^2 + r^2\dot{\theta}^2 + r^2\sin^2\theta\,\dot{\phi}^2)$$

Lagrange's equations are

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{r}} - \frac{\partial T}{\partial r} = m(\ddot{r} - r\dot{\theta}^2 - r\sin^2\theta\,\dot{\phi}^2) = Q_r$$

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{\theta}} - \frac{\partial T}{\partial \theta} = m\left[\frac{d}{dt}(r^2\dot{\theta}) - r^2\sin\theta\cos\theta\,\dot{\phi}^2\right] = 0$$

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{\phi}} - \frac{\partial T}{\partial \phi} = m\frac{d}{dt}(r^2\sin^2\theta\,\dot{\phi}) = 0$$

These may be compared with the cartesian equations

$$m\ddot{x} = \frac{x}{r}F(x,y,z)$$

$$m\ddot{y} = \frac{y}{r}F(x,y,z)$$

$$m\ddot{z} = \frac{z}{r}F(x,y,z)$$

in which the force function F appears in all three of the equations of motion, while two of the three Lagrange equations are independent of the detailed nature of the force.

Two particles, fixed separation. In this system there is one constraint, the particles being a constant distance d apart, and so there are five degrees of freedom instead of six. Choose as generalized coordinates the cartesian coordinates X, Y, Z of the center of mass and the polar angles θ, ϕ of the line joining the two particles, as in Fig. 2. Then, because the kinetic energy is the sum of the kinetic energy of the center of mass and the kinetic energy relative to the center of mass,

$$T = \frac{m_1 + m_2}{2}(\dot{X}^2 + \dot{Y}^2 + \dot{Z}^2) + \frac{1}{2}\left(\frac{m_1 m_2}{m_1 + m_2}\right)l^2(\dot{\theta}^2 + \sin^2\theta\,\dot{\phi}^2)$$

The equations of motion may be written down immediately, the generalized forces being evaluated from Eq. (9). There is one equation for each degree of freedom, and the constraint is automatically satisfied.

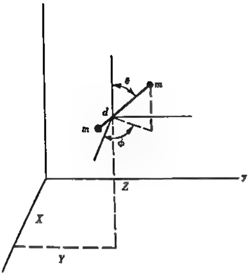


Fig 2 XYZ rt d t f th t f f th d mbb ll m m θ d ϕ th p l gles f th f th d mbb ll t f th g t th t f m d p ll l t th fix d set f

Conservative systems In m ny p bl m th f es Q_j e de bl f m p t ntial Th

$$W = \sum Q \, dq = -dV \tag{11}$$

and th s

$$Q = -\frac{\partial V}{\partial q} \qquad \frac{\partial V}{\partial q} = 0 \tag{12}$$

Wh n thr so t t t defi f t lled th Lagr g by

$$L(q\,q\,t) = T(q\,q\,t) - V(q\,t) \tag{13}$$

Th n th q t f m u b m mply

$$\frac{d}{dt}\frac{\partial L}{\partial \dot q} - \frac{\partial L}{\partial q} = 0 \tag{14}$$

h h th m t mm ly t ed f rm f Lagr equ u

E mpl f *f L* A mpl b t n p bl m ll t t th f g l ed d t nd h w th e f ppl t f Lagr g qu u h *T* d *I* l t ly y t bt Co d th d m l y t m f tw q l ses *m* c ect d by p g f t n g t t *k* Let th d pl m ts f th m f m th r equ l b m po t b *x* d *x* n u l

w t od w coo d t $q = x - x$ d $q =$ + Th $V = kq\ /2$ d

$$T = m(q\ + q\ )/4$$

g $L = T - V$ Lagr g q t f th t n bl a

$$\tfrac{1}{2}m\dot q_1 - kq = 0$$

and $\qquad \tfrac{1}{2}mq_2 = 0 \quad$ or $\quad q_2 = 0$

The s l t n to th first of these different al q ti ns i $q = A$ in $\sqrt{2k/m}\,t$ (ett g $q_1 = 0$ at $t = 0$) wh h i a mple harmon bration of the tw ma e Th co d equ t merely t tes th t the accel t n of the ce t of mass f the syst m s

N conse t t e y t ms Form (14) i al t e e if th y t m i not c n erv t e pro- ided wr te

$$Q = \frac{d}{dt}\frac{\partial V}{\partial q} - \frac{\partial V}{\partial q} \tag{15}$$

as i the c e of h g d p ticle in a l ct o- ma t field He e

$$V = e\left(\phi - \frac{\quad A}{}\right) \tag{16}$$

whe e ϕ a d A a th l r and ecto p t tials f th fi ld r p t ely the charg f the p t l v the p rti l l ty a d c is th elo ty f l ght

Cy l c o d n t If L d n t d pend pl tly on part l rd te say q th

$$\frac{d}{dt}\frac{\partial L}{\partial \dot q_k} = 0 \qquad \frac{\partial L}{\partial q} = \text{nstant} \tag{17}$$

H e q_k lled n g rable y l coord ate d $\partial L/\partial q$ i tegr l f m t I th e m ple f th ce t l f field g n p evi u ly ϕ may b g d

T t l gy By f Eq (14) it s e th t

$$\frac{d}{dt}\left(\sum^{f} \frac{\partial L}{\partial \dot q} q - L\right) = -\frac{\partial L}{\partial t} \tag{18}$$

He ce f L d n t d p d pl c tly n th t m th p n

$$\sum^{f}\left(\frac{\partial L}{\partial \dot q} q - L\right) \tag{19}$$

t gr l of m t U lly t th t tal gy f th y t m S HAM LTON S EQUATIONS OF MOTION

C nj g t m m tum Th q t ty

$$p_k = \frac{\partial L}{\partial q} \tag{20}$$

d fi ed t b th m m t m j g t t th o- d te q (If Lagr d t t b f the p f d pat f r the c j g te m m t m m t me d fi d a $\partial T/\partial q$) Th m m t m t ar ly l m m n t m d fi d N wt m h har t d p d b th n th y t m d n th t f th coo d t q If q n gn bl c d t t j g t m m t m n t t f

Kinetic momentum For a charged particle in an electromagnetic field the Lagrangian may be writ ten

$$L = \tfrac{1}{2}mv^2 - e\phi + \frac{e}{c}v \cdot A \qquad (21)$$

and the momentum conjugate to the cartesian co ordinate x is

$$p = \frac{\partial L}{\partial \dot{x}} = m\dot{x} + \frac{e}{c}A \qquad (22)$$

The quantity $m\dot{x}$ is called the kinetic momentum The kinetic momentum is related to p much as the kinetic energy is related to the total energy If ϕ and A are independent of x it is the momentum p and not the kinetic momentum $m\dot{x}$ which is a con tant of motion

Relativistic systems The equations of motion of a relativi tic particle may be written in Lagrangian form The simplest way to do thi is to replace the kinetic energy T by another function τ of the ma s and velocity so as to get the derived form namely

$$\frac{d}{dt}\frac{\partial \tau}{\partial \dot{x}_k} - \frac{\partial V}{\partial x_k} = \frac{d}{dt}\left(\frac{m_0 \dot{x}_k}{\sqrt{1 - v^2/c^2}}\right) - \frac{\partial V}{\partial x_k} = 0$$

Here m_0 is the rest mass of the particle Thi is accomplished by setting

$$\tau = (1 - \sqrt{1 - v^2/c^2})m_0 c^2$$

which r duces to T in the limit $v/c \to 0$ The equa tions of motion in this form are till valid in only one reference frame becau e the time and the coor dinates are treated on different ba es *See* RELA TIVISTIC MECHANICS RELATIVITY [P M S]

Biblio raphy H C Corl en and P Stehle *Clas sical Mechanics* 1950 H Cold tein *Classical Mechanics* 1950 H B Lind ay *Concepts and Methods of Theoretical Physics* 19 1

Lagrangian function

A function of the generalized co rdinates and e locities of a dynamical y tem from which the equa tions of m tion in Lagrange form can be deri ed (*see* LAGRANGE S EQUATIONS) The Lagrangian f nc tion is denoted by $L(q_1 \ldots q_f, \dot{q}_1 \ldots \dot{q}_f, t)$

For y tems in which the f rce are deri able from a potential energy V if the kineti energy is T

$$L = T - V$$

If the sy tem i contin u rather than di crete the Lagrangian function L i the integral of a Lagrangian density $\mathcal{L}$

$$L = \int \mathcal{L}(\eta \text{ grad } \eta, x_1, x_2, x_3, t)\, dx_1 dx_2 dx_3$$

where $\eta(x_1 x_2 x_3)$ describe the di placement of the medium at the point $(x_1 x_2 x_3)$ Th equation of motion are in thi ca e

$$\frac{\partial}{\partial t}\frac{\partial \mathcal{L}}{\partial(\partial\eta/\partial t)} + \sum_{j=1}^{3}\frac{\partial}{\partial x_j}\frac{\partial \mathcal{L}}{\partial(\partial\eta/\partial x_j)} - \frac{\partial \mathcal{L}}{\partial \eta} = 0$$

This formulation of Lagrange equati n appl es to the motion of a gas containing ound waves to a vibrating jelly or to any medium where discrete ma es are replaced by a continuum [P M S]

Bibliography *See* LAGRANGE S EQUATIONS

Lake

An inland body of water mall to moderately large in size with its surface expo ed t the atm phere Mo t lake fill depre sion belo the z ne of atura tion in the surrounding oil and rock material Generically peaking all bodie of water of th type are lake although mall lakes u ually are called pond tarns (in mountains) and le fre quently pools or mere The great majority of lakes have a surface area of le than 100 quare mile (mi) More than 30 well known lake ho ever exceed 1 500 mi² in extent and the largest fre h water body Lake Superior North Ameri a covers 31 180 mi

Dimensions of some major lakes

Lak	Ar	V l ( ] pr) 1000 ac e-ft	Sh e- l n	Depth A ft	Depth M ft
Ca p n S	169 300	1 300	3 30	6	3 050
S p	31 180	9 00	1 860	4	1 000
V to	6 00	180	130		
A l S	(33				
H on	3 010	3 0	1 680		
Mi l g	100	4 660			8 0
Ba k l	13 300	18 00		300	5 000
Ta g y k	[illegible] 00	8 100			4 00
(t B	11 190		1 300		
(t Sl	11 [illegible] 0		1 36		
Ny	11 000	6 800		900	310
[illegible]	9 910	136			
Wi p g	9 390		1 180		
O i	10	1 390			
B lk h	11				
La l g	000	1			
Ch l	[illegible] 00				
M ho	1 000				
I y	3 00				
On g	3 61	61			
R l lf	3 1				
N g	3 089	87			
Atl l k	3 08				
T i	3 00				
H l	11				

A fl t tes

M t lake are relati ely hall w features of th earth urfa e F en me of the large t lake ha e maximum d pth of le than 100 ft (Winnipeg Cana la Balk h U S S R Albert Uganda) A few howe er ha e maxim m depth wh h ap pr a h th e of me ea Lake Baikal in th U S S R i al t a mile d p at it d epest point and Lake Tanganyik Afri a i abo it 0 9 mi

Be au f their h ll wn lake in g n ral m y b on id red e an nt f at ir of th e rth urf e with a r lati ely h rt lif in geo l gi al time F ery lak i a in f rm a bed t wh h th lime t carrie l by infl wi g str am i dep ited As th s diment a c um lat the t r age c p ity of th b in i r d ced g tati n en

c o hes pon the h ll w ma g ns and eventually th lak may d s ppe r M t l k als ha ≡ sur f e o tlet Ex ept at elevat ns ery near sea level a tr am wh ch flow from uch an outlet gr d lly c t th ou h the b rr er f rm ng the lake b m. As th l el of the outl t s l we ed the c pa ty f the b s n is al o ed c d and the d ap-pear of the l ke red

Variations in water character Lak s differ a t the lt c t nt of th w ter nd a t wh th r th r a e t rmitt nt ≡ perma ent M t lakes a e comp ed of fresh w t l t m a e m e alty th n the oc n Ge e lly peaking number f ater b d e h ch a e c lled a a e actually salt lak examples a th Dead Ca pi n and Aral se s All lt l ke re f d nder de tt o sem rid limat wh e the ate f e porat on s h gh e gh t p e nt an utflow and the fo e a d scharge of alt t th ea M ny le ≡ arid ro l kes i term tt nt om time ex t g only f h rt p i d afte he vy ra a d dis ppe ng nd t te ev p r tion Th s lakes are called play in N rth Am ri a h tts n N rth Af a d th names el wh re In s h rg th s fa e a a d v l m f perma e t lakes m y d ff r e orm u ly f om w t to dry a so

Th t r f th mo pe man t alt lakes dif f rs gr tly the d gre of l ty d the typ of lt d l ed Comp red to typ al c an w ter (pp m t ly 35 parts p tl an l ppt) m lt l kes e y lty G at S lt Lake water has a d l ed l d nt nt ab ut *fo* t mes that of sea water (150 ppt) a d the D d S a b ut eve times (246 ppt) Some l the l g r alt l ke h e m h low d l ed ol d nt nt s th A l S a (11 ppt) a d the Ca p a S (6 ppt) The mpo t n of lt d p d p rt n th geol g l h a ter f th d a ≡ e d h rg g int th lak p to th ge l th lake d in part th e es f i p r t n o e i fl w A at t n pp hed the s lts mmo n u fa at r a e p e c p t t d n u h an o d th r m gnes m hl de d l m hlo d em n in sol t lte th r lt h p j t ted

Lak w th f h wat r ls d ff g tl n th compo t n f th w t ≡ u l th bal bet een t fl w d utfl w f esh lake w t r m po t t nd t ume th mp te d l d w l d h a ter t c f th w t s f th fl w ng t am—w th th l k age h l ttl n fl n e Lakes tl a l gg h nflow n rt cul ly h rv nflow ≡ ter h ve m h o t t w th m g l g t t tend t ha e w t s w th h gh g n t t Thi may he ob rv d n mall l kes p d r g wh re dra n ge m es th gh a v p g aphy l gl l m l kes f rmed w th d g a ha t g r t l l m t m ph l n trv r k t nd t ha e h d sol ed solid o t t Th s Lake S p th t m j d n g f m th Lau t n Sh ld ha d sol ed sol d t nt f 0.05 ppt Th wat r f C m l Lak n th high Alp S t zerland has a d ol ed s lids c ntent f only 0.0085 ppt Lakes w thin l me t ne or dolomit c drainage areas ha ≡ a pron unced calcium car b ate and m gne um a bo at c ntent As in all surface w ter d ol ed g ≡ n tably oxygen al o are pr e t n lak waters Und r f w pecial t uat o s as rate l ke in lcan c a ea sulfur or other g es may be p ≡ e t in lake water influenc g col r ta te and chemi al eacti ≡ f the wat r *See* SURFACE WATER

Basin and regional factors Mo t l ke ar nat ral a d a l rg prop rti n of them l e in d pr s s n of gl cial ≡ ig Thu alpine l cation and regi n with g und m a ne or gl ci lly eroded exp ures re th t s f man of the wo ld lake The l kes of Swit erl d M nn ota and F nl nd re pe ti ly re w ll k own ll t tion of the e types

Lake m y b formed i depre io s of diff ring glac al gi (GLACIATED TERRANE) (1) ter ra n er ded by c ntinental gl er with the u f ce differ tially deepe ed b y ic abr ion of r cks of vary g h rdnes a d resi tanc (2) al ley e d d d fle e t all by alley gla ers (3) ci q ie (glaci lly ded alley head n mo ntai n) (4) l teral m raine ≡ ri r (5) f nt l m ra e b rrie (6) valley gl cier barr er (7) eg l nt in the d p t of gl l drift r g und m ine

Lake a e p t cul l my rta t *rf* fea tur in th p nepl d tent ks f th Lau nt an Sh ld a d tl Fe n a dian Sh ld of o thern E r p The l ke gion f n thern N th Am ica wh h nt th Lau ≡ t an Shield pr b bly h one-fifth t o e-q arter of t fa e n l ke Ma y t eams the e e s are inter rupt d mo than h lf the r total length by l ke Lakes on the h eld a a rul a land tudded a d h t em ly r gular outl ne The m t p m ne t l ke l n the h ld them l e Ma y u h lake n recently ≡ o red h eld h v fr h h d k r i th h h res t n to o t th utl t ≡ a f g lly l w t e m g d t a d l ttle l m nt ca ied th b d ng d dep t t m t ns a e l w A a lt the l fe f all b t th m ll lake r th e a p b bly w ll b m d in term f wh le g ol g p r d

Some l kes in gl c lly formed d p es on s w ll ther b may b e n d d b r er lake The gla l l ke a e f rmed n gla l d ft beh nd l t t f ntal m ra b rr e l dd t dep e ns f ffici t d pth to conta n a lak m y b f med by (1) ed m nt depos ted by t ams (all i m) al o t e m b rne g t ti e d b a tr dam th d t b ta i a d b d d e e u e f th l we Mi s pp V l l ( ) l d l d n m u t n u a (3) nd d e (4) i rm b h a d c r t bo ed m ts al g th h r s f l rge bod es f wate (5) l fl w (6) ≡ t fic al o ma mad b ri

A l rg p r t g f lak i f nd n th r the gla lly f rmed r barrier f rmed depr

sions However a few other types of depressions contain lakes (1) craters of inactive volcanoes or calderas (Crater Lake in Oregon is a famous example) (2) depressions of tectonic or structural origin (Great Rift Valley of Africa includes Lakes Albert Tanganyika and Nyasa) (3) solution cavities in limestone country rock (4) shallow depressions cau■ a dotting of lakes in many parts of the tundra of high latitudes

Conservation and economic aspects The lakes created behind manmade barriers are becoming more and more common features to serve multiple purposes Examples are Lake Mead behind Boulder Dam on the Colorado River Lake Roosevelt behind Grand Coulee Dam on the Columbia Kentucky Lake and other lakes of the Tennessee Valley and Lake Tsimlyanskaya on the Don

Both natural and manmade lakes are economically significant for their storage of water regulation of stream flow adaptability to navigation and recreational attractiveness A few salt lakes are significant sources of minerals Recreational utility long important in the alpine region of Europe and in Japan is now a major economic attribute of many American lakes Economic value is generally increased by location near substantial human settlement Most of the world's lakes however are located in regions where they have only minor economic significance at the present time [F A A]

Bibliography R E Coker *Streams Lakes Ponds* 1954 P H Kuenen *Realms of Water* 1955 F C Lane *The World's Great Lakes* 1948 U S Army Corps of Engineers *Survey of Northern and Northwestern Lakes* Great Lakes Pilot Bulletin 60 1951

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Streamline flow of a viscous fluid which satisfies the Navier Stokes equation of motion In laminar flow the fluid moves in layers without large irregular fluctuations (see TURBULENT FLOW) Laminar flow occurs at low Reynolds numbers This corresponds to the conditions of small velocities and dimensions of bodies to very large viscosity or to small density of the fluid Laminar flow plays an important role in several practical problems

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Bibliography S I Pai *Viscous Flow Theory* vol 1 1956

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Any of several species of very primitive vertebrates belonging to the class Cyclostomata Lampreys are elongate cylindrical animals without jaws scales or paired fins They are dark grayish to bluish black in color and are richly supplied with a slimy m■ to protect their thin skin

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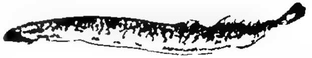


Sea lamprey (Petromyzon m); length to 3 ft (From E L Palmer Fieldbook of Natural History McGraw Hill 1949)

Th e both f e h w ter and m pecies M t f th m a e f l ttle imp ta the o e c pt bei g th Great Lak ace of the e l p ey *P t myz m rin s* I re ent ve th d p edat f th large lamp y h rtually dest ed the l ke tro t nd wh t fi h fi heries in the C t Lak depr i g comm l fi h m f m'll f d ll

I th p g lamp ey mi te p t m or fr m th t c a tal treams t b uld a ne t of pebbles All ad lts d ft p wn ng Th l rv dev l p i th m d q uet eddies and stra plankt nd c deb from th w t th o gh gll sl t u til th tt maturity wh ch m r q re 3–7 year Wh they cl ang t th ad lt f m th d ift d w tream t l g r water h e the t k p the pa t l fe M st pa t l mp ey lt ad lt f a per d f about o e r

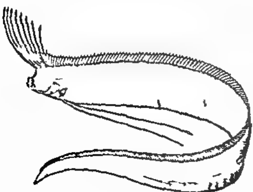
Th e r l ev l no p a iti sp alled b ook l mp ey The ly d l pment d app a e irt lly d t cal t th t of th p t pec Th y d t feed ad lts p n soo ft r t a f rm g d d e few d y S CYCLOSTOM AT (CHO DATA)

[J D B]

Lampriformes

Th ribbonfi h a fi h p h d th alle lo k n th All t og th Alth h th fi hes e d f rm th y ha h r ter th t d fi e th de f a t opt yg fish h h appe t b r l t d t th B r f rm The fi e c p d f ft r th dor l b l 7 a t r p n n th t phe d bon p e t the p l c fi th with 1 17 ray the p l g dl rt d b tween the c ds a att hed t them th wimbladder w th t d t mes d a d p th t re b t a d th m ll lly p ot t le M t spec e l ge nd som mm ly th e f e p nt t

Th l mp d f m fi h d te f m th Ol go They mp 5 f m l 8 R t g d



Oarfish R g l gl l gth t 20 ft (Aft D S Jord d B W E m Th F h f N rth nd Middl Am US N H M B ll 47 1900

perhaps 12 pecies All are oceanic l ing at hal l w t mode te depth *See* ACTINOPTERYGII

[R M B]

Lamprophyre

A y f a g p f gneous rocks cha te i ed by a porphyriti t t e which al d t l ge crystal (phe ocrysts) f d k l ed (mafic) m er l (biotit mph b le pyr xene or ol e) app et i aphaniti (t v ibly c y t l line) mat x As a gr p the e dark ck are char act ed by (1) a bundan f mafic m e als i associati w th alk l ch feld p (2) the pre en f mafics both a ph rysts d in th ma t x and (3) n ab nd nce of m fic ph cry t in the ab ce of feld par ph n cry ts Lampr phyre a chemically un l They h e a l w s l a con tent a d h gh i mag e um nd alk li e tent S PHENOCRYST

Varieties of lamprophyre M ny m t of l mpr phyre e known but nly th more common ar sh wn n th ac mpa y g table

C mmon l mp phyres

Pri pal d gnos m fic	Principal f ld pa		W hou f ld pa	
	Alk l f ld pa	Pl gioct se	W h ol	W hout ol vi
B te Hornbl nd	M Voge	K rsa t te Spessa ta	Al oi	O h t
B k k		Campton te	M och qu t	Fou hi

M tte t sit k sant t d sp sa t t The f m t mm n types e mi ett ge ke s t te nd pe art t The fi st tw ar c mm nly f d to a sy nit lamp phyre the l st t a d t lamp phyres U d the m ope l g h g l pl t f b tit sh w z al stru t e with p le yell w m gn si m rich c t s nd red b wn h b d r l some rock the e rystal ar c rr d d Sl de p i m needles of g n b own h r bl d a *mm n* Py x ne er lly d p d a g te b t in me rock a tt m h ugt b d nt Ol i r r m t type b t i c mm pes art t

A la ge p rt n f the k m t ix i m p ed f f ld p r Pl g o l se (lb t a des) form g l g n or p ly d l p d l tha nd may h w z l tr ct with l m h c es d od m h b d s *P t h feld* p r lly rth l d c u i eg la t ct gul g n nd c mm nly n l e th m al a ab nd nt tiny g a n Q a t m y b m t tu nt a d wh n p t i int tt l A e ry m l i l de ap tite ph nd m g ett t

C mpt u Th mm lamp phyre c mp t n t h t i d by th p e c f ba ke ik t d l b ad ite d feld p Pyr b t t a d l may m y n t b p e nt

Al t d u ch t t These t e e r e b t t l mp phy They f ld p f but rv m l l t r f ld p th d Al o t ch a te ed by lep d m l phe oc y t d by th p es-

sions. However, a few other types of depressions contain lakes: (1) craters of inactive volcanoes or calderas (Crater Lake in Oregon is a famous example); (2) depressions of tectonic or structural origin (Great Rift Valley of Africa include Lake Albert, Tanganyika, and Nyasa); (3) solution cavities in limestone country rock; (4) shallow depressions cause a dotting of lakes in many parts of the tundra of high latitudes.

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Bibliography H. E. Coker, *Streams, Lakes, Ponds*, 1954; I. H. Kuenen, *Realms of Water*, 1955; F. C. Lane, *The World's Great Lakes*, 1948; U.S. Army Corps of Engineers, *Survey of Northern and Northwestern Lakes*, Great Lakes Pilot Bulletin 60, 1951.

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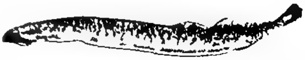


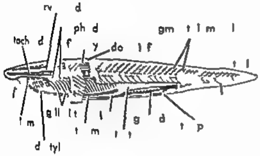
Sea lamprey (Petromyzon marinus), length to 3 ft. (From E. L. Palmer, Fieldbook of Natural History, McGraw-Hill, 1949)

Spec fic t tment q ite as ff t e as with the f t m thod of dentific t o There a e t mes when streptococ m t be l b l d The e o l de ep d m s nd tudies the r tion patte n f th ho t, e pec lly ch n unde ble rheumatic fe er where pre e t ght For h ch t d the Lancefield erol g c tech q are of great alue *See* MASTITIS (cows) RHEUM TIC FEVER SCARLET FEVER STREPTOCOCCUS [P L.B]

Lancelet

A y m mber of the ubphyl m C ph l h d t phyl m Chord t There e o ly tw gene a *B ch t ma* d *Asymmet o* and a total f nly 30 pecies *B a ch toma* i the b tte k wn d th a mal u lly m t when refe e is m d t th l elet or t is m mm nly c lled mphi us

La c l ts l n hall w wat burrow g loose d w th th h d p t d g They ccur n th w rm nd tempe at s and e wid ly d tr b ted i cl d g pe alo g the so th rn c a t f the U ted St t They e som t me ed l food



Th l l t mph B h st m t l bout 2 l g (F m T I St d R L U g G l Z l gy 3d d M G w H ll 1957)

Amph bo t 2 r l s l gth d sm l in appe r c t a m ll t a pa ent fi h It h t h d the f ll l gth of th body w th a se es f pa ed g ll sl t pen g t n t l ty The e m ll d t ct d l t b l ne s y tem w th n a te r e l rg m t La el t re f p rt l t r t t ol g t bec th y ppe r cl t th n est l l f th ert b tes They r m l an t my t th l r l Cy l t m ta *S* CE H LOCHOR ATA [J.D]

Land use planning

Th d ected of la d a d the nat l r o th f m f the p ed t rm d p po f the soc t l t h h g l n g t s A pl g u t m y be n i d id ll d w h ps h f m t t f f t l d r l est t b d n it m y be mb f d d al h p i cl d g both p t a d publ l d l th l tt e th pla g u t lly

cides with the boundaries of some go ernment l ju i d ction h a a city county t t some reg l c mb at f these

Th object e of la d use planning on an nd d al ow hip may b imply that of maximizing the net i c me of th owner The object e of land u e planning by a publ agency however is more c mplex a d i inte ded t maximize long range c mm ty b fit Ach ing the c mmunity go d often requ res me l m t t n upon the freedom f i d idual owner t s thei l d as they choo La d pla i g deci i ns req b l nc g con flicts of int est m g ind id ls and betwee pri te and publ c e d ors Th e dec ions bas ically i l rec ncil g d ffe i g val e structur m g the ind du ls compri g the mmunity within the pl nning a

Origin of land use problems The tra tio from an ea ly s mpl e omi a d s c l orga za t n t a m d comple nat l ec my has e ted ma y land u e p oblem The fro t er men li ed d ectly f m the l d a d their depe den up ther was l m ted T d y peopl a e j t a depende t upo the la d but their rel t hips t it a d t ea h ther e m e c mpli ted At the s me time d mand re m e ried the pre su e o the la d e ce m re t t t d the need f l nd u e pl i g m re mp lli g

Th e cha cte t cs of tal a d co m hi t y nu t ed nt mpor ry l d u pr blem F t tr g mp t t e f r es pr moted by a ph l ophy of f ee p ate e terp ise u ged rap d u ord l d expl t t of la d nd it e e Th xpl tat n was ha act r ed by e t us ste d f te method k ow t mode n t hn logy It so ght t m x mi e im m d t m eta y r t s to the pe to r their th lt m te b efits t cety T d y th meth d d p ttern f early u e e decl ed w t f l t rms f cu e t need te hn logy nd o omi s P bli pol y attempt to sat fy l ng r nge need f ciety m d q tely a d t d s ch w te by ff e c g method d p tt rns f la d us th gh r s pl g eff rt

Sec d e ly l d e pl tat dem n tr ted l t tle de t d g of tu al l d p b l ty The pl w foll wed the a n m ny s wh ag i c lt c t d a well as f t th plow b k th pl i m ny pl s whe er ps r n t a mp t bl with the l mate a m r d ght s t t f ag d th plow ha tur d the s d f fi ld wh h by t e f s il h cters ti s and s f e l pe ca t pp rt c ltu t with t r p d d s il d plet Th e d t h e du ed p bl c pp rt f l nd u e plan ng d gn d t h i g m th ds of h sbandry i l e w th th t l cap b l t es f th l d

Th d e ly c ty dev l pm nt, th b ce of l d p l y a d pl n re lt d nd s c mn te m t f de t al i d t al d mm l l d Co s qu tly denti l fte ff ed d ff t d l and c mme i l d d t l t pr s f l d t ach p

ence of melilite perovskite olivine and carbonate in the matrix Ouachitite is devoid of olivine and may carry more or less glass and considerable augite as phenocrysts

Monchiquite and fourchite The rare types monchiquite and fourchite lack feldspar but carry more or less barkevikite in addition to augite biotite analcite and glass Monchiquite is distinguished from fourchite largely by the presence of olivine

Alteration products Lamprophyres are highly susceptible to weathering and many are so completely decomposed that it is impossible to do more than approximate their original mineral composition Common products of alteration include carbonate chlorite serpentine and limonite

Occurrence Lamprophyres occur most commonly in small or shallow intrusives (dikes sills and plugs) and are frequently associated with large bodies of granite and diorite Lamprophyre dikes may form parallel swarms or as at Spanish Peaks Colorado may form groups which radiate from a common center

Formation Lamprophyres form in a variety of ways Some are products of direct crystallization of lamprophyric magma (rock melt) others represent older rock which has been converted by metamorphic or metasomatic action Normal basaltic magma may be made lamprophyric by assimilation of foreign material That such a process has operated is suggested by the presence in some lamprophyres of abundant foreign rock and mineral fragments The mafic phenocrysts commonly show strong resorption indicating they were not in equilibrium with the adjacent liquid Early formed mafic crystals may settle out of a deep slowly crystalizing magma Clusters of these may be reincorporated in the late alkali rich fraction of the melt just before it is erupted to form lamprophyre at higher levels

Some normal basaltic dikes appear to have been transformed to lamprophyre after solidification This metamorphic or metasomatic change could have been accomplished by vapors or fluids which were driven out from the deeper crystallizing portions to permeate and alter the solidified portions above Similar emanations from deeply buried granitic masses may be channelled along dikes of basalt or diabase in the overlying rocks and convert them to lamprophyres

Some bodies of lamprophyre which resemble dikes may not actually be intrusive They may have formed when solution or fluids from depth moved up along fractures and reacted with the adjacent rock and converted it to lamprophyre *See* DIABASE IGNEOUS ROCKS METASOMATISM [C A CA]

Lancefield differentiation scheme

An accurate mean of identifying most streptococci The procedure was determined by Rebecca C Lancefield and it applies to those streptococci the β hemolytic types which have major significance Strains from many sources can be classified in terms of their natural host with ability to produce disease in this host as well as in other hosts However the immunochemical (serologic) differentiation system of Lancefield depends on the presence within the bacterial cell of a specific carbohydrate the so called C substance which determines the group The definition of the group depends on the precipitation of the C substance in a clear bacterial extract with appropriate rabbit antisera Designations of the group now 13 in number extend from A through O with two alphabetic omissions

Those streptococci of Group A are almost always responsible only for human illness Most strains of Group B are from animal and are especially important in producing mastitis or udder infection in cows Group C is unusual in that it includes both animal and human pathogens and distinction cannot be made by this method alone Group D streptococci are found in dairy products and in the intestinal tract of man and animals They are a cause of urinary tract infection and of subacute bacterial endocarditis which is an infection of the inner lining of the heart, especially the heart valves Subacute bacterial endocarditis is a complication of congenital or rheumatic heart disease Both human diseases represent the ability of ordinarily benign organism to be pathogenic when there is some basic deformity which interferes with normal function Streptococci of Groups E and N are found in milk cream and cheese but have no relation to infection Groups F and G are occasionally human pathogen while H and K strains do not provoke illness People may harbor those of Group H K and O which are almost uniformly innocuous Dogs likewise merely carry Group M streptococci but canine illness can be caused by strains of Groups L and C

F Griffith at the same time the Lancefield system was developed utilized agglutination to define types within each group Agglutination is a serologic method in which intact organisms are clumped by appropriate typed rabbit antisera There was a time when both methods were used one for the determination of group the Lancefield precipitin test with type selection by Griffith's agglutination test It was later noted that the type found by both methods need not be in complete agreement This led to the study by Dr Lancefield and her associates of the bacterial antigen or chemical substance concerned It was found that two protein M and T were involved in differentiating types within groups Only the M substance of the Lancefield method was specific for each type of microorganism while more than one T substance could be present

Serologic classification is not commonly employed since it is time consuming and not always necessary In a clinical hospital laboratory for example streptococci can be satisfactorily and rapidly recognized by their typical appearance on suitable growth medium Appropriate signs and symptoms in the patient are supportive evidence

of the eso ce pla ner Th s imp r t e in the e ptte n f hum n ettl ment wh ch s evol ng in the U ted States The o rlapping metr pol es m t be planned t meet the ba i eg onal n d fr ate a t d p al tr n portat o and op spa e for l ght ai and recr ation with due re gard t th natu al capabil ty f it en ronment to ta n optimum le el of reg nal ec n m c op portu it a d oc al am n t es Community requ r ment and the nat al e nm t l ap l lity h ld find ex el t on in a n w type f n t gr ted re l des gn

Sec d rd r to fa litate so de pul lic plan n g dec t da d d c ite a t gu d la d u e allo ti mu t be dev l p d by th t d nt s d pr tit f la d u e pl n ng a d be c por ted n p blic la d p l H t icall th f e ent p c n m ha elied upo the m ket t allo ate l nd and all r es The h ghest p c det rm ed th u e to wh ch th e w e uld l put The ed f r l nd u pl n g an es f m th f lu e f th mark t alway t llocat la d t the be t u f om the tandpo nt of th mm n t Th il pl n ng s t me t t hall g it m t dev l p gu de f p bl e sour e allw t wh h will more ly eb e the comm n t g od in th e re a d fo th e p poses wh r th m k t f d want

Th d f land pl n ing s to be mad n i t u m s of democ acy mp m nt e q ed in the m th ds by wh h c l ch i of th maj r ty find e p i th pl nn es F l pl n d s wh ther th appr l a ne l r t i lo la d u e ll at o f p c fi pla h uld be m de by p ple of th m mu ty th h th p ti f th p l t l p c es Land u e pla n ng in the fut e m t d l p han l th ugh wh ch t an b m t cu f t serv g the p l t c l p nd n r p nd i g to t w th ught nd pe im t ti n h ld be appl ed t the c mpo it n a d ele t on f the pl n i g org n zat o n th h f r a tr t re th t w ll p e entat n f the mm n ty a d p o de p t t ag n t m f m self seek g te est

F rth de bett r t th t pl all b arr d ut, l r r l t h p m t be tab l hed b tw n the pla n ng a th r ty nd th g n es wh h e e p r f implem ntat n Ch ter ti allr a c ty pl nn ng mm n i establ hed som hat rt f m th mi n r l g rnm t th nly p l l tho ity labl t impl m t th pl n In gly regi al pl n g bod es wheth o i nt d p m l t la g m t polt eg n r t la g e d el p m t r g ha a pl g d a pe ff ct f wh h n gl go nm t l body ca rr a th mpl m t g tho t B th f these t t mak it d ffi lt t m h th pl n g g w th th dm n trat e g In rnt es f th pol ti al nd adm n t t en es hall ged t d r i t tut l f rm a d p oced es th gh h h th pl g p oc and the publ c p w r f implementat on ca act r pon ibly one t th ther

In the m d tw nti th cent ry e e ce and te h nology an wr t f om the e rth pract c ll any th ng The criti al problem in land u e planning of the futu e ar s f om the diffic lty of deter m n ng wl at i ou ht The problem are n t s i nt fi nd technol g in the t nal e b it they are human n They inv l e r c ncili g differ nt human d ir and rg n zin f r c mp r t de c s ns and p ogr ms f act o Th hall n i to fi l m a s of one ptu lly nd m th d l gi lly m ld ng the natu al e c l a ed techn l gie into a e r nm ntal fr mew rk with the applied so i l cie ces to pr d ce a l nd u e heme to r man be t S AGRICULTURE FOREST A D FORESTRY s e lso FOREST CO SERVATION RANGE LAND CONSERVATION SOIL CONSERVATION WATER CON ERVATION [L F C]

Bibl o raphy Se CONSERVATION OF RE OURCE

Landing gear

Th e p rt f an a ft tr tur wh h erve t upp t th r raft when t n t i the a r fi wh el b ake h ck t it dra tr t nd mi cell n u eq ipm nt t as t acting me ha n m tee i g me han ms himm damp and door the mp n t f n ai cr ft la di gea F r sp c l p rp s tf wt l and tir may b epl d w th k d r k A land gge r q ed n ll pil ted a cr ft It p o de a me f ppl g f c n rm l t th g d f ffi i nt m gn t f a d d at n t d t the flight p th fr m int r e t g th und t on pa all l t th g i d dur g l nd g a m an f ta d g f wa d m t n by of b ak and a m ns for p t ng p it on ng and m v ng the a rpla e o th gr u d R qu me t f land g ge mpo e a we ght pe lty f 10–20 of th st u tu al we ght f the i plan fr m wh ch th h le recei e be eft o ce t a borne The l n p f rma a d pa l ad b cau e of th we ght a d ign r t g g at d al f att nti n to the la ding ge when a n w air pl e i des g d

Landing gear arrangement Cur tly th m t wid ly c pt d a r n em nt i the t icy l l nd n g a (Fig 1) Th ar ang m i plac a n e g w ll i rw d f th c nt f g vity n the fu l g d t o ma n gea l ghtly aft f the ce te f gra ty w th uff i nt d ta ce b twee them t p d tab l ty ga t ll g d ri a ya d l d ro w d d r ng ground m n r The o p e ent n g whe h ak s a appl d The n e a wh h s lw s t d often eq ipped with power teer ng t ll g o d m n u ng

A ld ti al be fit fr m tr cy l nfigu t r that (1) th enter f gr ty f rw d of the m in g a lt n i a figu at n wl ch i nh ntl d ect lly t ll d i g la d (2) the p l t i bl ty i g od (3) th flo f th ai c aft i ly l el whe th a pl n n

ble economies in such services as transportation, power, and waste disposal. As deterioration of the central city set in, residences, stores, service establishments, and industries favored the suburbs for new location. This situation makes forcefully evident the need for public decisions and public controls on major aspects of land use in the central city and in the mushrooming suburbs of every metropolitan center of the country.

Principal planning areas. Early land use planning efforts sprang from two apparently distinct and different problems areas: (1) rural areas, where the planning task has been concerned largely with giving more conscious direction to the use of land for natural productive purposes (crops, forage, forests, wildlife, fisheries, or water flow) and the goal has been to direct the use of the land in accordance with its capability; and (2) urban areas, where the planning task has been principally concerned with space arrangement of major urban land uses. In this case the goal has been to design the city layout to achieve greater convenience, safety, and economy in urban living.

Rural land planning emphasizes the development of land use patterns which serve man's long range needs and at the same time reflect the natural resource capability, that is, the physical and biological limits beyond which long run depletion of the land resource will result. Increasingly, private land operators are learning that production according to land capability is good business. There is also increasing recognition by the public that there is a major common interest in intelligent rural land use planning. The Federal government provides various inducements and aids designed to improve rural land use. Local and state governments are experimenting with land use controls, for example, zoning lands for forest and pasture which are unsuitable for crops, designating lands well suited to farming as agricultural, and marking out for future subdivision those areas best adapted for that purpose.

City land use planning, originating from the desire for the city beautiful, has moved from an emphasis upon aesthetic design to functional design. It attempts to anticipate long range needs for urban services through the study of growth trends and to design a pattern of land use which will promote convenience and economy in supplying urban services as well as an aesthetically pleasing space arrangement. Recent policies of both Federal and state governments encourage cities to conduct a continuing planning program.

Since the great depression of the 1930s, both Federal and state governments have cooperatively organized studies for the purpose of developing plans for improved productivity of land and related resources of various large natural regions of the nation. The Great Lakes Cut-Over Region and the Northern Great Plains were areas early subject to such regional studies. The creation of the Tennessee Valley Authority in 1933 marked a further emphasis upon regional resource planning. TVA and later endeavors in river basin development have had as their primary planning objective the discovery of improved economic opportunities and social amenities which could be realized by a planned use and management of the land, water, and related resources.

This objective stands in contrast to the early, more limited view of the city planner, forester, and conservationist. The early city planner looked at the blighted city and visualized its rehabilitation. He studied trends and sought to design his city layout for the inevitable growth. He had little concern with questions of planning to promote growth. The early forester and general conservationist dwelt on natural limitations and emphasized protection measures to avoid continued misuse. Later, measures based upon land capability and scientific husbandry were formulated. These measures first emphasized the repair and rehabilitation of the physical and biotic environments which suffered from past misuse. Gradually the increase of goods and services from natural resources has become an additional justification for these conservation measures. Comprehensive regional planning now purports a positive integration objective for land planning designed to achieve maximum net social benefit (economic and noneconomic) for the use of the land now and in the future.

The growth and importance of regional resource development is indicated by the rapid expansion since World War II of Federal, state, and local resource planning activities. Notable are programs in regions such as the Ohio River Basin, the Missouri River Basin, the Columbia Valley, the Central Valley of California, the Arkansas-White and Red river basins, the St. Lawrence Valley, the New England and New York region, and the Delaware River Basin. In addition, hundreds of local organizations, such as watershed associations, various special districts, and intergovernmental planning committees, have sprung up in response to land use problems in a variety of areas. Often these smaller regions may be dominated by a vigorous urban center. Here rural type resource development problems intermingle with the problems of space allocation and design of the spreading urban area. Land use planning during the last half of the twentieth century is challenged to meet the need of a new planning area, one composed of overlapping metropolises and involving new admixtures of rural and urban land use problems.

Land use planning and the future. Current trends in land use planning suggest four developments in its concepts and practices which should characterize the future. First, the problems of integrating the space-use considerations of urban planning and the resource-use considerations of rural planning will demand increasing attention of professional planners, governmental officials, and interested citizens. Conceptual and methodological interchange and adaptation should take place between the space design orientation of the city planner and the resource capability orientation

PLA E WING STRUCTURE. S als SHOCK ABSORBER CORD [J E S]

B bl g phy H G C nw y *L di g Ge De sign* 1958 B Milw tsky and F E. Cook *A lys s of La d g G ar B h* NACA Rept 1154 1953

Landing ships and craft

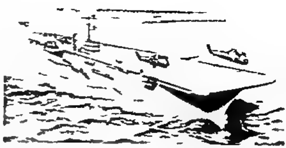
Comb t ves l employed amphibiou warf e t l d pe el a d upplie A w de ariety f l d g hp a d land g c ft g m ize f m m ll b t t h p 450 ft in le gth w sed W ld W II Nea ly all wer w l p type de l ped pecially f amph b s warfare These e sel w e ge lly d g ted by th let te LS (La d g Sh p) or LC (La d g Craft) ather tha by am s Cr ft le s th n 130 ft i l gth we d ed o ea g ing d wer t a p t d t th as a lt ar by h p A th d n ty f l d g ess L a tru amph b an ap ble f oper t g l d a well s i w ter w also sed n W ld W II

D i g th po tw pe iod ew f t were m ted t th LSD (Land g Sh p D k) a d LST (La d g Sh p T k) by m k ng them l g r a d fa te i o der t p ed p the hea y l ft f ta k tra ked d wh led h l a d h vy m b l tr ct d e mb t q ipm t

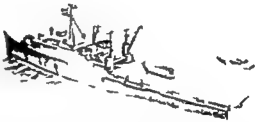
T meet the n ed of the le g d p al f h ps, a d i m i th pe d f mph b s pe t ew c n ept a d t h q a e q d Th mo t ig ifica t ew de el pm t is the use f h l pt t hurdle e nd g t b hind t gly d f ded bea h Hel pt s h e th ad d l c p b l ty f l d g t oop q ipm t a d uppl i h p-t h e m me t t f st r t f sp d Kn wn e t la lt th p ttern h ll d f r new typ f h ps ch a the LPH a d LPD l th ti l a lt ph e th e h p l m at th W ld W II p tt rn of the tag g f r th t fe g of t oops d q pm t f m g d pe l sh p i t m ll l d g craft

Amph b ous assault ship (LPH) The LPH i m l t m ll i c ft e h g flight deck h g r p e a d n l nd t u t f h p nd fl ght t l Th LPH 2 sh w F g 1 i 600 ft l g d d pl 18 000 t

Amphibious transport dock (LPD) Th LPD l d t p q pm nt d pple by m f mba ked l d c ft amph b h l a d h l pt l th d gn f th h p mph wa pl l n th n pt f a mpl t f t m b l b l ed f th LPD ld epl e t g a d l d g h p e t n type f mph b s pe t T d i th ap d l d g f g th h p q pped w th y mp h l g d lev t Th p h l ty f b l la t g d l k afl t g d d k p tmt l d ng aft t ter th t m w ll fl t (th LSD) h q pm t he l d d d tly t th l d g ft Also th l d g a n d by meth d es f th h dl g f th types f g Th LPD 1 l F g — 510 ft l g



Fg 1 Th LPH 2 d g d to l d t p d p pl by m f h l pt (Off l U S N y ph t g ph)



Fg 2 Th LPD-1 l d g ft i th gh th t (Off l U S N y ph t g ph)

Fg 3 Th LSD-31 d t l h l d g ft d h l d fl t g dryd k (Offi l U S N vy ph t g ph)

nd h f lll d d pl em t of j t d 14 000 t

Landing ships The LSD h th apability of p rt l bm g n like flo t ng d yd k Sm ll cr ft e t a w ll whi h e t ds lm t th f ll l th f th h p The m i f the LSD i t c rry a d l h l ded l d g craft d h cl n amphib s a lt a d to r de l m t d d ck ng d p rs f m ll c ft n the f rw d a e Th LSD 31 h wn in F g 3 510 ft l g d d pl e 12 000 t n wh the well i dry

Th LST rri t k a d h les to f mph b a a lt mb t A l ge t nk d k xt d aft f m th b w doo m t g t b d h ged d tl d p be h f m b lt amp V h l nt the al o b

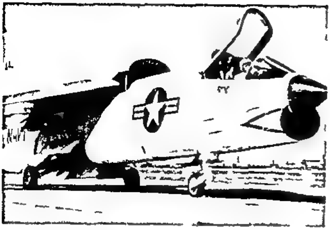


Fig 1 Typical tricycle landing gear on F8U 2 Crusader (Chance Vought Aircraft Inc)

the ground contributing to ease in loading and to passenger comfort and (4) at touchdown the position of the main gear aft of the center of gravity results in nosing the airplane over onto the nose gear reducing the angle of attack and reducing the possibility of the airplane s rebounding into the air

Another arrangement still used extensively is the tail wheel landing gear (Fig 2) Two main gear struts are located slightly ahead of the center of gravity well spaced laterally to provide lateral stability a third wheel is mounted on the fuselage near the aft end of the airplane This arrangement is usually lighter than the tricycle landing gear It suffers in comparison with a tricycle gear because of the increased problems associated with vision ground maneuvering and braking

Other arrangements are often used because of special problems associated with a particular design The bicycle landing gear used on the Boeing B 47 is an example this gear requires outriggers for lateral stability A gear of this type will usually be heavier than the more conventional type but often is attractive for over all performance Research airplanes such as the X 2 and X 15 often use skids instead of wheels because ground maneuvering is less important on airplanes of this type space and temperature considerations control the choice Helicopters and VTOL aircraft often use unconventional arrangements because many of the considerations for ground maneuvering are less important

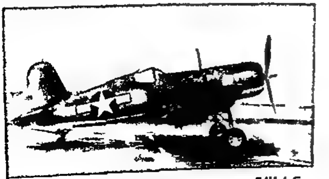


Fig 2 Typical tail wheel landing gear on F4U-4 Co

Landing gear design The primary working part of any landing gear is the shock strut which supplies the force as the airplane sinks toward the ground turning the flight path from one intersecting the ground to one parallel to the ground The most efficient shock strut is the oleo-pneumatic strut (Fig 3) It operates by generating a force as oil is pushed through an orifice When the wheel of the landing gear first contacts the ground the tire deflects to stop the unsprung mass of the landing gear (tire wheel brake and piston of the oleo) As the airplane continues to sink the piston in the shock strut forces oil through an orifice causing a force which changes the airplane s flight path

To obtain a better force time relationship a metering pin is often used to change the orifice

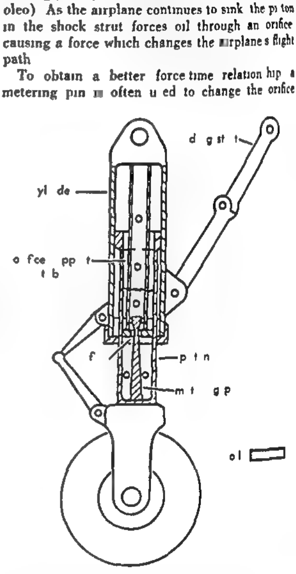


Fig 3 Diagram of oleo pneumatic shock strut

size as the shock strut strokes Air pressure in the strut extends the gear after it is compressed and also acts as an air spring suspension system for the airplane during taxiing

As alternates to the oleo leaf springs rubber springs and oil springs have been successfully used

To provide for the drag load during braking and the impulsive drag load due to spin up of the wheel after initial contact strength must be provided usually by a drag strut If the wheel can be castored as a nose wheel or tail wheel is likely to be provision must be made to prevent shimmy usually by the use of a shimmy damper See AIR

d est mates a i tance in lett g ontracts and peri f the ork d e by th ntractors

P ject u d tak by landscape archit ct s de l g p ks a d recreati n a a e l t t bd o h ghway d parkw ys and land api g f r indu tri in titution cemete ie nd rge p al estates

Training required M t land cape a ch tect e llege-tra ed p l ts Th t ai g i des de gn d g b ild ng ar h tectur (u u ll 4y e) gi ee g rveyi g b ild ng a d c tructio m t r l co t est mate a d robl m l nd pe de g Co m il a d lant sci a e met m cluded

La dsc p a ch te t e is prim ly n American fes n. In E gla d m st p je t m ol g t t t l d p bl dev l pment h dl d by g er d ar h te t land g of p te red d th d f dec ati e pl t gs d arily d ne by the la d c p g d e The rm l d pe gard t g lly appl ed t the d g g of nat ral tic ll gs It w a school th t a in E gl d d g th etee th t ry ppo ti t th f rm o geometr d gn that d m nated l d dev l pm t befo then

Landscape nursery service Th a p al za t n f the fi ld of la d pe ch t ture The erv l m ted t m ll ivi a d publ p blem t tes the dev l pm t f h m pr p rt e d m ll est t Op at s ally as ted th a n ery ha dl ll ph se f proj t from d gn pl th gh n t u t n d pl t g d upply all ce ry m t l Tra g f l dsc pe n ery ervi ally l d th b c s e pl d a ed w rk ls d pl t n e u ery man g m t rs y g d e rthw k d m co t tio f ch tructu es a t pools nd w ll S CIVIL E GI EERING [J P P]

Landslide

Th pe pt ble d wnw d sl d g o fall f l t ly dry m f arth rock r mb t f th tw Th t m i m time e tended t c er r l t d fl wag m me t l d g rthfl w m dfl w d d b l h All bel g t the f m ly f m ss-m em t p es wh h ge f m l w soil-creep t b pt r kf ll

La d l des gr g ally d tt t bec f b tte d t d g f th pl f ma movem t n th sh p f th l d se pe d bec f m g t d nd f q en f l d l d p bl m e la g t d fill m d f d m pe h ghw f d tio d th r g ee i g p j t La d l des nst th h ghw y d r l d f th U ted St tes d Ca d $10 000 000 a y n tru t d m t a e a d k wn b t l g ad l t l m t n i d ect l es I the ll t l g m y l es l t h ye d rectly d ectly bec u f l d l d d ma l t t phes som t me w pe ut wh l al l ges.

Landsl des al called land l p range f m low angle r th l w sl des to vertical falls S me fl wage may ce mpa y l d g for example fol lowi g i t l lippage of a wet l m ss or in th very rap d tw d p eading of the t gue of a l ck l d r ro kf ll wh ch may s st al m t e t ely of dry r S MASS WASTING

Types of landslides Ba ed n type of m ement r l t e rate a d k d f materi l invol ed l d l des ca b ep ated i t fi e mai types— l mp d b l de debr f ll r k l de and rockf ll (Fig 1)

Sl mp The d w w d lipp g of mass of rock o u c n ol d ted deb i m t g as a unit e e al s bs d ry u t hara t t ti lly with b ck w d tation n a h r zontal is p allel to the l pe i k own sl mp Mo eme t is ually rath slow d may be intermitte t di placeme t mall rel t e t the e f th m The m jor

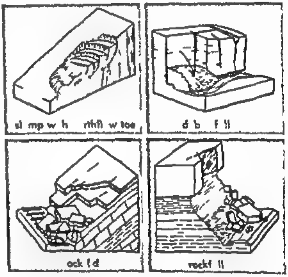


Fig 1 Typ f l d l d s.

sl p urf ce s typic lly p haped and ca e t w d the sl p bl ck i both ert c l nd ho tal ect The m d a e t th h ad f slump may b b ke t m y t pl ke i la ly t lted block A m h p nd l ke may f m betw e ba kwa d t lted bl k d the l ff f m wh h t des e ded Sl mp g lly re lt f m rem l f pport l w n th l pe Th may c r by t l rt fi i l de c tt ng by fl w ge e the ub q eo ly n upwa d b lgi g th fl w Sl mp mm n n t l el ff d b k d th des f t fi al t d fill

D bri l d Th typ f l nd l d i a rap d d wnw rd l d g d f rwa d ll g f u l d t d th nd r ky d l u lly w th the f rmat o of n rreg l h mmocky dep t. At the t m f m m t th mat l m t be f ly dry th m w ld t k th ha t f rthfl w D b s-l de e ally th sm ll a d fte e lt f m t l r rt fi l u d tt g f a l p

carried on the main deck The LST 1173 shown in Fig 4 is 446 ft long and displaces 7800 tons

The LSM (Landing Ship Medium) is a beaching ship with an open well and a bow ramp Its design was derived from a combination of LST and LCU The LSM is 204 ft long and displaces 1095 tons

The LSMR or Landing Ship Medium (Rocket) is a conversion of the LSM The LSMR provides close in fire support with a barrage of rocket bombardment for an assault landing operation The LSMR is 204 ft long and displace 1276 tons

Landing craft The LCU or Landing Craft Utility (assault) discharges tanks mobile equipment general cargo and personnel directly onto the beach The LCU is designed for limited voyages and usually is carried to the unloading area by an LPD LSD or LST The LCU 1613 shown in Fig 5 is 135 ft long and has a combat landing displacement of 370 tons

The LCM (Landing Craft Mechanized) is used in a ship to shore operation and lands on a beach to discharge vehicles or cargo A typical LCM is 74 ft long with a maximum displacement of 127 tons and is designed to carry one heavy tank 60 tons of cargo or 200 troops

The LCPL or Landing Craft Personnel (Lead) is a dual purpose boat for guiding other landing craft in an assault wave in a ship to shore operation The LCPL is 36 ft long and has a capacity of 4500 lb of cargo As a personnel boat it has a crew of 3 and carries 17 men

Amphibious vehicles The LVT (Landing Vehicle Tracked) is an armored amphibian It can negotiate a surf up to 15 ft high and discharge 34 men inland The LVTP 5 (Fig 6) is 30 ft long

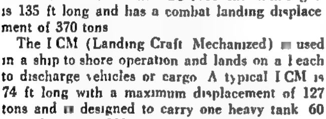


Fig 4 The LST 1173 designed to discharge tanks and other vehicles directly onto a beach (Official U S Navy photograph)

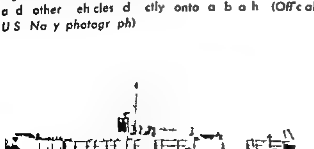


Fig 5 The LCU 1613 used to discharge vehicles equipment and personnel directly onto a beach (Official U.S Navy photograph)

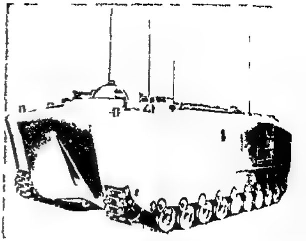


Fig 6 The LVTP 5 an armored amphibian (Official U S Navy photograph)

Fig 7 The DUKW developed for landing on sandy beaches (Official U S Signal Corps photograph)

and has a cargo capacity of 6 ton in water or 9 ton on land

The BARC (Barge Amphibious Resupply Cargo) is a wheeled amphibious vehicle for over the beach handling of cargo Used by the U S Army it is 63 ft long and has a cargo capacity of 60 tons

The BDL IX (Beach Discharge Lighter) used by the U S Army carries vehicular and other types of cargo on the main deck for ship to shore landing operation When retracting from the beach it is assisted by a hydraulically operated ram The BDL IX is 338 ft long displaces 4126 tons and is capable of transocean voyage

The DUKW (Truck Amphibian 2½ Ton) commonly called duck is used by the U S Army to transport cargo or personnel on land or water (Fig 7) It is 36 ft long and has a cargo capacity of 5175 lb See SHIP NAVAL [H J M]

Landscape architecture

Defined by Charles Eliot one of America s first landscape architect as the art of arranging and fitting land for human use and enjoyment Landscape architecture is an applied art founded on the premise that use and beauty are compatible and that neither is complete without the other

The services of the landscape architect is similar to those of a building architect in offering consultation preparation of reports plans specification

k fan t n of th e ll ct r and emitter The nmur Ch ld l w appl s to a cl e a p xima n to ther electrod g tr es as w ll Th coa al cylind with the nner cyl nder th thod it lead t de at on f om th true v lue the current de ty f at mo t 13% See DIODE ctUM SPACE CHARGE [E C B A]

anolin

h hyd u heep s wool fat (p m rily choles- f este s f h gher fatty a id) de ed a a by rod t fr m the prepar tion f raw wo l f r the p n The crude w l f t pur fied melted m ed ith about 30% w ter d all wed t k d t a ft p le y ll w ungu ntl ke ub-

La l w d ly u d a b e f m ll nt t p t t a d be ut fy th k d l o in t m- poo t make the ha r l b ittl and m e lus- t u It ha sl ght ant ptic ffe t a d h gh re ta e t r nc lity and it may be fo th se r so th t it has c nt nued wid e as a ba e for k n tm t Act ally lan l n h d s ab rp- t n f the med at thr u h th k n a om p red t ther h t n e uch s l e l o lard La l n ol ble in alcohol ther hl ofo m a d be S FAT A D OIL, NONEDIBLE [C C O]

Lantern slides

P t e t p ent p ctu o gla film which m be ewed by p j t n o t r fle t g c en o n hand e s r de s n wh ch th t re is pr j cted o t the r r of d ff g e r en S nd d s ■ e Un ted States 3 by 4 B t th, 3¼ by 3¼ C nt ent l 85 by 100 mm t med at Co t tal 10 by 0 mm 2¼ by 2 m t t r (th m t p p l) 2 by 2 The l t size am d a ed e a ywher The apert re s e of the m ked pi t r s h e b en t nd rd ed Alth ugh bl k and wh t t a p e es h d be n mad n 2 by 2 n ze from m n t e m n gat in e the e l day of th t t pe f m ra th gr t r a p p la ty f th by l d a d th ppropr at proj c tor a d l d n f t the mi tur cam et itself) t ms fr m th int odu t n f K d k ■ film d its t n fr m pro e g t the a dbo d K d k R d M u t a th K da l d t n p r y

Sl d r pr j ted e t n l p j ctors (p al l t n) n t g f c nt ated wour l l ght nde t m h ld (o h nge) f r th l d a p j t n le a d (u al) a bl f r ool g th sl d (s e PROJEC N SYSTEM ■ TICAL) T ng t n fil m t l mp g ner lly w th p efoc ed b ed n w tt ges f m 150 t 1000 dep d g r n th p o- jected p t m l m attag a f h m se Th focal l gth f th l g erned by th p ject d t e d scree s e Ma y t f l l ha g r m d in l d g h nd feed g l les at a t m a h ng r wh l c

tie two sl de (on i l anged wh le the other is project d) ca tt whi h ■ rrie a gr up of l d and f ed lid n and out emiaut mati ally and a maga ine of lide which are a oc ated with t mer a d are fed and changed f lly uto mat ally ■ me holders ca ry long rolls f film nd film trip

Sl des pa ticula ly n the min atu r i e can b ewed in hand ie er or tabl iewe The forme have mea fo ll m nati ■ the l de po nting t t th ky r t a lamp or u g l mp in l ded in the ı wer f e l d l att r wall outlet op rat n, and a imple mag if i g len They ar mad f r gle r ter l de T ble iewe ar really m ll p oje t rs gi ng n image f m de at m gnifi at for ewi g a rea pr ject r n and ha manu l or aut mat c sl de ch nge Large d play tra sparenci (18 by 60 ft th ca e f the K lak Col ama i Grand Cent al Stat on n N w Yo k C ty) u bank of l ght gi un f rm illumination r a diffu ng screen immediately beh nd the ■ cture [W C]

Lanthanide contraction

The n me g en to an unu ual ph n men n en u t red in th r e e rth e es f element The d of th at m of th memb er of thi eri de- ea lightly as the t m numbe increa es Starti g w th element 58 n th e pe dic t bl the b l nc ng el tr n fill in n in er i mplete 4f h ll as th h rge n the u l in e e e Ac rd g to the theory of at m t u t r thi hell n h ■ 14 ele tr ns o tartin w th elem t 58 r um th re a e 14 tru r r earths La than m h n le t ns the 4f h ll m ha l a d l t t m 14 The 4f electr pl y lm t r le t h m c l ale ce all ra e e rth can ha e 3 le t s ther le c hell nd they all e t a tr alent n ol tion As the cha ■ n the u le in rease the rare e rth s all le t n e p lled n el er t th n l u that th rad f the r e ea th on d a sl ghtly a th mp und g r the rar e th r e A y g n mp d f th are e rth y l kely t t ll ze w th the m st ucture a a y ther e th ll we er the l ttic p ram te b me maller d the ry tal d n er a th c mp nd p d e th es This c ntra ti n of the latt ce p m te kn n the l nth d n t a t n F m ny mp u d the l tt p am t d ea l p tt way a r tl r es a d wh n th ntr t n h ■ r g e ed f r w s t ll e f m des lop F q e tly b th ery t l l f rm c n b ob erved f numb of th l m t Fo th r n th ar th e es f p t l r t t t to e t t b ma y of th p r m t d te m ng th p pertie f a ub t ce a be k pt ta t whil th latt p s g n b ri d s m ll i em t acr s th e ies

Th t m d io rad f at m are n t l rl d fi ed Th at m n be p l ri ed by the

Debris fall A relatively free downward or forward falling of unconsolidated or poorly consolidated earth or rocky debris constitutes this type. Debris falls are common along undercut banks of rivers, from walls of rapidly eroding gullies, and in steep excavations.

Rockslide This type applies to any downward and usually rapid movement of newly detached segments of the bedrock sliding on bedding or any other plane of separation. Rockslides may form wherever dipping strata or jointed rocks are interrupted downslope by any kind of cut. They include some of the greatest of recorded landslides. A rockslide in the Gros Ventre River valley of Wyoming in 1925 (Fig. 2), for example, displaced 50,000,000 yd^3 for a total of about 2000 ft down a dip slope of 18–21° and dammed the Gros Ventre River. *See* ROCK MECHANICS.

Rockfall The relatively free falling of a newly detached segment of bedrock of any size from a cliff or steep slope is called rockfall. Rockfalls are common along headwalls of glacial cirques and on wave-cut cliffs. They are a constant hazard on vertical rock cuts along transportation routes, where the fall of a block weighing even a few pounds may disable a vehicle or kill its occupants. Many of the world's largest landslides have been combinations of rockslide and rockfall. Rockfalls into fiords and mountain lakes sometimes produce enormous waves capable of demolishing waterfront villages. *See* EROSION.

Fig. 2 Gros Ventre landslide of June 23, 1925, showing scar and lower portion of slide debris, Lincoln County, Wyoming. (USGS)

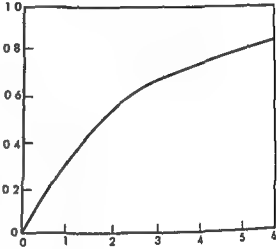
Prevention and control of landslides This depends primarily on avoidance of unsuitable construction in areas of old slides or recognizable mass movement hazard. Other basic measures for prevention and control include excavation to remove fallen or unstable material; drainage of unstable or potentially unstable material to reduce weight and increase shear resistance and to prevent additional water from gaining access to dangerously placed masses; placement of retaining structures such as piling, buttresses, retaining walls, cribbing, and wire fences or netting to keep fallen rocks off communication routes. Warning devices are sometimes used to close railroad blocks when fallen rocks or debris slides enter a right of way. [C.F.S.S.]

Bibliography. *Landslides and Engineering Practice*, NAS-NRC Publ. 544, Highway Research Board Spec. Rep. 29, 1958; C. F. S. Sharpe, *Landslides and Related Phenomena*, 1938.

Langevin function

A mathematical function which is important in the theory of paramagnetism and in the theory of the dielectric properties of insulators. The analytical expression for the Langevin function, displayed in the accompanying figure, is

$$L(x) = \coth x - 1/x$$



Plot of Langevin function.

If $x \ll 1$, $L(x) \cong x/3$. The paramagnetic susceptibility of a classical (non-quantum-mechanical) collection of magnetic dipoles is given by a Langevin function, as is the polarizability of molecules having a permanent electric dipole moment. In the quantum-mechanical treatment of paramagnetism, the Langevin function is replaced by the Brillouin function. For further discussion *see* DIELECTRIC CONSTANT; PARAMAGNETISM. [F.A.; F.K.]

Langmuir-Child law

A law governing space-charge-limited flow of electron current between two plane parallel electrodes in vacuum when the emission velocities of the electrons can be neglected. It is often called the three-halves power law and is expressed by the formula

$$j(\text{amp/cm}^2) = \frac{\epsilon}{9\pi}\left(\frac{2e}{m}\right)^{1/2}\frac{V^{3/2}}{d^2} = 2.33 \times 10^{-6}\,\frac{V\,(\text{volts})^{3/2}}{d(\text{cm})^2}$$

Here ϵ is the dielectric constant of vacuum, $-e$ the charge of the electron, m its mass, V the potential difference between the two electrodes, d their separation, and j the current density at the collector electrode or anode. The potential difference V is the applied voltage reduced by the difference in

The fir t and la t m mbe s of th s quati n form th fl theo m mely that the tot l flux (f l eat if is temper t r) o C is zero

If (xy) i harm nic i th el ed d k b ded by the ci umf re ce γ a d $f(\ )$ the c r j o d g analyt f n ti n, w c take th e l p rts f both membe of th eq ti exp Ca hy s tegral form la

$$\omega = \rho(\cos\theta + \ \sin\theta) \qquad d\ = (\ -\ o)\,d\theta$$

$$f(\omega) = (x\ y_0) + (\ \ y) = \frac{1}{2\pi i}\int \frac{f(\ )\,d}{\ -\ o}$$

$$= \frac{1}{2}\int f(\ )\,d\theta$$

$$(\ \ y) = \frac{1}{\ }\int (x\,y)\,d\theta$$

Th l t qu t presse Ga ss m n l e theorem th t the g of $u(x\,y)$ γ is the l e t the cente of γ F m tl th o m it f l l that f n t n harm n at a point $(x\ y\ )$ can ot h tro g local ma imum (r min mum) the d c n h a k l cal i mum (r n m m) o ly if id t lly n ta t th o gh ut t neighbo hood f (ω y) If $(x\,y)$ i h rm i n i bou ded eg n D c nt i th e re pond g cl ed reg n $\overline{D}$ the m mu a d mi m m of $u(\ y)$ occu n the bou d ry of D f a ma m m mi mum occ s int ri r t D the $u(x\,y)$ d t lly c t t th gh ut D

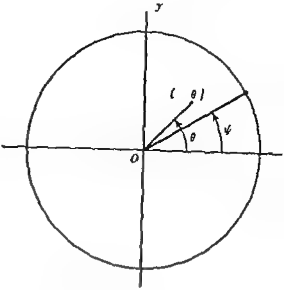
If D i a bo nd d g n w th b und ry B d f t ti l es $U(x\,y)$ a gned n B the Dirichlet pr blem the p bl m f d termin ng a unctu $(x\,y)$ harmo n D c ti uous o $D + B$ eq al t $U(\ y)$ on B If D i c ula g n a J dan r gi n r a y n path l gic l e- om th D ri hl t p bl m h ol t ec s- a l (by th b f no tr al m m and n m int to D) I If D c la k f d s (e ll t t o) th D r hl t roblem f D sol ed by P o int g l

$$(\ \theta) = \frac{1}{\ }\int \frac{(\ -r^2)U(\psi)\,d\psi}{\ -\ \omega\ \ (\theta-\psi)+r^2}$$

ng polar oord at s $(\ \theta)$ w th p l th t D If D i less l m t y eg n b t w th nooth b d ry B th D hlet p blem l ed y G ee f rm la

$$(\ \ y) \quad \frac{1}{\pi}\int_B U(\xi\,\eta)\,\frac{\partial g}{\partial\ }\,d\ (\xi\,\eta)$$

he i d t tl i i m l in th f la (reen f t $g(x\,y\,\xi\,\eta)$ h rm D pt at ( ) t and q l t e d th neighborhood f $(x\,y)$ ha th f rm l $g[(\xi - \ )^2 + (\eta - y)^2] + g(\xi\,\eta)$ h re $(\xi\,\eta)$ h m at ( ) If th bo d y B not mooth th f m l c n be xp sed i rm f h rm m e t d f $(\partial g/\partial n)\,d$



C c l d k D of d

Num u er es expans on (for xampl F ur er ser s) can b u ed f r the ol ti f the D r hlet p blem fo a i s eg n

n Dimensional relations Tl e f going emarks pply to Lapla e quati n w th two nd p d t iabl th f cts (but n t th meth d of p oof u g a lyt c fu cti n) apply al o i th ee o m r d men ns Th s i th e d men ns p nt d t that of matte f ma s m t p int $(x\ y\ z)$ h a p t tal d fi ed a

$$u(x\,y\ ) = \Sigma m\ [(x - x_k) + (y - y_k) + (\ -\ )^2]^{-1/}$$

wh h i harmo xcept n the po t $(x\ y\ \omega_k)$ E cept t s h p t t the f c (Ne tonl law of gr t ti) xert d b th d tr but n n u t xpl rat y part cle at $(x\,y\,\omega)$ ha the c m ll ne ts $(\partial\ /\partial x\ \ \partial u/\partial y\ \ \partial u/\partial\ )$ d the compo- n nt f the f e in ny di ect on s the direct on l d i at of $(x\,y)$ th t d recti Se POTEN TIALS (MATHEMATIC) SPHERICAL HAR IO ICS [J L W]

Bibl og aphy O D Kellogg *F nd t l Th o y* 19 9 *of Po-*

Laplace s irrotational motion

Lapl e eq at f rrotat n l m t n f n n d mp ble fl d is the p rt l diff en t l qu t

$$\frac{\partial\ \phi}{\partial\ _1^2} + \frac{\partial\ \phi}{\partial x_2} + \frac{\partial\ \phi}{\partial x_3^2} = 0$$

wh e x_3 re ectangul Carte n coord nat in n t rt l refe nc f ame and

$$\phi = \phi(x\ ,x\ ,x\ ,t)$$

i th elo ty pote t al The flu d l lly m po nt u u in th thr e resp t e r ct gu l r oo d n t d cti s re g by $u = \partial\phi/\partial$ $= 1\,2\,3$ M e gen all i a y inert al coo d nat i t m the qu t n i d (g d ϕ) = 0 and th elocity ect i = gr d ϕ

Atomic and Ionic radii of rare earth metals

El m nt	Il I A 3+ n	Met l cry t l t t b	M t ll c I A c	d
Sc		l p	1 (1	1 6 80
Y		l cp	1 8 37	1 7780
La	1 061	l p	1 88	1 8691
C	1 031	fcc	1 8 18	
P	1 013	l p	1 83(3	1 8 01
Nd	0 99	l p	1 8 90	1 8139
Pm	0 9 9			
Sm	0 9(4	l n l p	1 810	1 7913
E	0 9 0	l c	1 991	
Cd	0 938	l cp	1 8180	1 786
Tb	0 9 3	l p	1 800	1 6 6
Dy	0 908	l	1 79	1 7 15
Ho	0 894	l cp	1 7887	1 1 8
Er	0 881	l cp	1 7794	1 7310
Tm	0 869	l p	1 7688	1 37
Yb	0 8 8	f	1 9397	
Lu	0 848	l cp	1 7 16	1 1 1

D t f om D H T mpl t 1 C 1 H D l n *J Am Ch Soc* 6 5 37 39 19 1

[b] D t f m F H Sp d l ng A H D n an l K W He rm nn *1 / C y t* 9(7) 9 563 19 6 l cp l e gon l lo p ck l f f t lc l c h m rl ml c b c, body t rel l

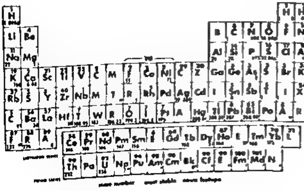
[c] D t f m K W H m n D t l tl d l l t d f m t m l l l

[d] D t f om K W H m D t l tl l b tw l y rs

neighboring atoms and there is no clear cut boundary between the electrons associated with one atom and another Therefore the atomic radii will vary somewhat from compound to compound and the absolute values depend on the method of calculation However if most of the parameters are assumed constant and the difference in lattice parameters in the rare earth crystalline series is attributed to the rare earth ion or atom then the lanthanide contraction becomes clearly evident Although scandium and yttrium are not members of this series the information is usually wanted at the same time and is given for completeness The atomic radii of the trivalent ion and the metal atom are given in the accompanying table *See* PERIODIC TABLE RARE EARTH ELEMENTS [F H SP]

Lanthanum

Element number 57 lanthanum La is a metallic element that is the second most abundant of the rare earth group Its atomic weight is 138 92 and the naturally occurring element is made up of the



stable isotopes La[1] 0 089c and La 99 91 It was discovered in 1839 by C G Mosander It occurs associated with other rare earths in monazite bastnasite and other minerals It is one of the radioactive products of the fission of uranium thorium or plutonium It is the most basic of the rare earths and can be separated rapidly from other members of the rare earth series by fractional crystallization Considerable quantities of it are separated commercially since it is an important ingredient in glass manufacture Lanthanum imparts a high refractive index to the glass and is used in the manufacture of expensive lenses The metal is readily attacked in air and is rapidly converted to a white powder For other properties of the metal *see* RARE EARTH ELEMENTS

Lanthanum becomes a superconductor below 5 K in both crystallization modification hexagonal or face centered cubic [F H P]

Laplace s differential equation

Laplace s equation in two independent variables x and y is

$$\frac{\partial^2 u(x\,y)}{\partial x^2} + \frac{\partial^2 u(x\,y)}{\partial y^2} = 0$$

and is of central importance in both pure mathematics and mathematical physics A function $u(x\,y)$ having continuous first and second partial derivatives and satisfying Laplace s equation in a neighborhood of a point is called harmonic at that point If a plane piece of tinfoil has its edges kept at a temperature which varies from point to point but does not change with time and if the flow of heat in the tinfoil is steady (that is independent of the time) the temperature $u(x\,y)$ at interior points of the foil is harmonic Likewise Laplace equation determines the flow of electricity (the potential is similarly harmonic) and the flow of any incompressible fluid

Two dimensional relations If $f(z) = u(x\,y) + iv(x\,y)$ is an analytic function $u(x\,y)$ and $v(x\,y)$ are conjugate functions and are harmonic (*see* COMPLEX NUMBERS AND COMPLEX VARIABLES) Conversely if $u(x\,y)$ is harmonic in a simply connected region D one may set

$$v(x,y) = \int_{(\ )}^{(\ )} \left(-\frac{\partial u}{\partial y} dx + \frac{\partial u}{\partial x} dy \right)$$

where $(x\ y)$ is fixed in D and $(x\,y)$ arbitrary in D It follows from Green s theorem that the integral over a path in D is independent of the path so $v(x\,y)$ is uniquely defined throughout D the function $u(x\,y)$ and $v(x\,y)$ are conjugate in D and $f(z) = u + iv$ is analytic there Under the same condition let C now be a regular Jordan curve in D if n denotes the interior normal of C the equation $\partial u/\partial n = -\partial v/\partial s$ follows from the Cauchy Riemann equations whence

$$\int_C \frac{\partial u}{\partial n} ds = -\int_C \frac{\partial v}{\partial s} ds = -v(\ \ )\big|_C = 0$$

Th first d la t m mbe s of th e q t t f rm t flux theo em mely that the total flux (f l at if is tempe at) o er C zer

If $u(x\ y)$ is harm c in th cl ed d k bounded by the circumf e c y a d $f( )$ the c r p l ing anal ti f cti n e ca take the r al p rt f both member f the q at xp es i g Ca hy i t g al f rm la

$$- _0 = \rho(\cos\theta + i\ \ n\ \theta) \qquad d\ = i(\ -\ _0)\ d\theta$$

$$f(_0) = (\ \ y_0) + (\ _0\ ) = \frac{1}{\pi i}\int \frac{f(\ )\,d}{-}$$

$$= \frac{1}{\pi}\int f(\ )\,d\theta$$

$$(\ _0\ ) = \frac{1}{\pi}\int (\ \ )\,d\theta$$

Th l t eq t n xp es es G me al e theorem, th t th a erag f (x) er y i th al t the ce t r f y F m th theor m t f l lo s th t a fu t h rmo c t po nt (y) anoth a e t ng loc l ma m m (or mi im m) th re a d n ha w ak local m xim m (mi m m) ly f de t lly n t nt th ugh t n ghbo hood f (x_0, y_0) If $u(\ y)$ h m ic n a bou ded egi n D co t i th rrespo d ing losed re n $\overline{D}$ the m im m a d mi m m f $u(\ )$ oc u th bo nd ry f D if m x m m mi m m oc i t ri t D th $(x\ y)$ id tically con tant thr gh ut D

If D is bo ded reg with bou d ry B nd if co tinu l e $U(x\ y)$ a g ed o B the Dirichlet probl m th pr bl m of d term ni g a fun ti n (y) harm i D tinu n $D+B$ equ l t $U(\ y)$ n B If D i a i ul regi n, J rd r a y n p th l gic l e g n, the D hlet probl m h a soluti neces sarily (b th b e f t l m m a d minima i t r t D) n q e If D ir ul di k f d u (see ll t t n) the D hl t probl m f r D l d by P son teg al

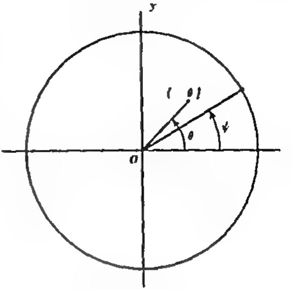
$$(\ \theta) = \frac{1}{\ }\int_0^{2\pi} \frac{(\ - r^2)U(\psi)\,d\psi}{-\ \ _0\ \ (\theta - \psi) + r^2}$$

g pol oo d n te (θ) with pole th c t f D If D a les l m t ry gio b t w th mooth bo d ry B th D hl t p bl m l d by G een f rm l

$$(\ \ ) = \frac{1}{\pi}\int U(\xi\ \eta)\,\frac{\partial g}{\partial\ }\,ds(\xi\ \eta)$$

h re d tes th i o n m l n th f mula.

Gree f t $g(\ \ \xi\ \eta)$ h rm D cept t ( ) t u d q l t r o B and in th ghborhood of (y) h th f rm $\ l\ g[(\xi - x)\ + (\eta - y)\ ] + g\ (\xi\ \eta)$ wh e $g\ (\xi\ \eta)$ is h rm ni t $(x\ y)$ If th b und ry B is t mooth, th f rm l be p ed t t rms (h rm mea in t ad f $(\partial g/\partial\ )\ d$



C lo d k D f d

Num r te xp n n (f r mpl F ur er series) ca be used f r tl sol it n f th Dir hl t pr ll m f e a i g n

n Dimensional relations Th f g g rema k pp ly t Lapl c t n w tl tw nd pe l nt bles th f t (l t n t tl n tl l f proof ng alyt fu t on) apply also i tl ree r m re d m n n Th i tl r e d m i ns, a poi t d t tlut n l m tt e f m es m at p i t $(x\ y\ _0)$ h a p t ti l defi ed

$$u(x\ y\ \ ) = -m\ [(\ -\ \ )^2 + (y - y\ )^2 + (\ -\ \ )\ ]^{-1}$$

wh h harm n c xcept in the p nt $(x\ \ \ \ )$ Exc pt t u h point the f c (N wt nia law f gr it t n) e erte l by tl di tr lut n n a unit plo t ry pa ti l t $(x\ y\ _0)$ h th c m pon t $(\partial\ \ \partial\ \ \partial u/\partial y\ \ \partial u\ \partial\ )$ d th mpo ne t f th fo e n ny d ect n i the d re t nal d r ti e f (y) i th t d recti n S POTE TI LS (MATHEMATICS) SPHERICAL HAR IONICS [J L W]

B bl g phy O D Kell gg *F dat of l o t t l The y* 1929

Laplace s irrotational motion

Lapl e q t f i r t t n l m t f an d i mp es ibl fl id th parti l d ff ren t l q t n

$$\frac{\partial\ \phi}{\partial x} + \frac{\partial\ \phi}{\partial\ } + \frac{\partial\ \phi}{\partial x} = 0$$

h r x x re tang l r Cart n coordi tes n intert l ref nc f am and

$$\phi = \phi(x\ x\ x\ t)$$

th el ty p tent l Th fl d eloc ty c m p e t the three r pecti e ctangu l d t d t a g n by $= \partial\phi/\partial$ $= 1\ldots 3$ M ge e ll m any n rtial oord nate y t m th qu t d $(g\ \ d\ \phi) = 0$ and th l ty ct i $v = g$ ad ϕ

...omic and ionic radii of rare earth metals

Fl m t	R I u A 3+ n	M t l c ystal t t ctur [b]	Met ll ra I i A	
				d
Sc				
Y		I p	1 6 4	1 6 80
I		I I	1 8 37	1 7780
Ce	1 061	I cp	1 88	1 8694
I r	1 034	f	1 8 [illegible]	
Nd	1 013	I cp	1 8363	
I m	0 99	I p	1 8 90	1 8 01
Sm	0 9 9			1 8139
Γ	0 964	I hcp	1 810	
Cd	0 9 0	bc	1 994	1 7943
Tb	[illegible] 938	I I	1 8180	1 86
Dy	0 9 3	I cp	1 800	1 7(6
II	0 908	I I	1 79	1 7 1
F	0 894	I p	1 88	1 74 8
Tm	0 881	I p	1 7794	1 7340
Yb	0 869	h p	1 7688	1 7 37
Lu	0 8 8	f c	1 9397	
	0 848	hcp	1 7 16	1 7171

D ta f D H T ıl t I C I H D ul n J 1m Cl Soc 6 37 39 19 4

[b] D ta f m F H Sp I I g A H Da n I K W H m nn 1 / Cry t 9(7) 9 (3 19 6 I cp h g I lo ı k I fc f nt I I I om I oml bc I o ly t I c I

Dat f m K W H m n D t al th I I t I f m t m I I pl n I

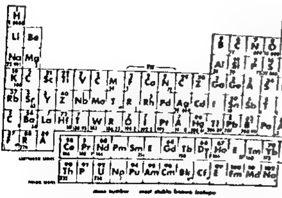
[d] Data f m K W H n D to al th I be twe n I ye

neighboring atoms and there is no clear cut boundary between the electrons as ociated with one atom and another Therefore the atomic radii will vary omewhat from compound to compound and the absolute values depend on the method of calculation However if most of the parameters are assumed constant and the difference in lattice parameters in the rare earth crystalline series is attributed to the rare earth ion or atom then the lanthanide contraction becomes clearly e ident Although scandium and yttrium are not members of this series the information is usually wanted at the ame time and is given for completeness The atomic radii of the trivalent ion and the metal atoms are given in the accompanying tal le Se PFRIODIC TABLF RARF FARTH FLFMFNTS [F H SI]

Lanthanum

Flement numl er 57 lanthanum I a is a metallic element that is the second mo t abundant of the rare earth group Its at mic weight is 138 92 and the naturally occurring element is made up of tl e stable isotopes La ¹ 0 089% and I a 99 91% It was discovered in 1839 by C G Mo ander It occurs associated with other rare earths in monazite bastnasite and other mineral It is one of the radioactive products of the fi sion of uranium thorium or plutonium It is the mo t ba ic of the rare earths and can be separated rapidly fr m other members of the rare earth series by fra tional crystallization Considerable quantities of it are separated commercially since it is an important ingredient in glass manufacture Lanthanum i parts a high refractive index to the gla s and is u ed in the manufacture of expen ive len es Th metal is readily attacked in air and is rapidl converted to a white powder For other propertie of the metal *see* RARF FARTH FLFMENTS

I anthanum becomes a superconductor belo 5 K in both crystallization modification hexag onal or face centered cubic [F H SP]



Laplace s differential equation

Laplace s equation in two independent variables x and y is

$$\frac{\partial^2 u(x\,y)}{\partial x^2} + \frac{\partial^2 u(x\,y)}{\partial y^2} = 0$$

and is of central importance in both pure mathematics and mathematical physics A functi n $u(x\,y)$ having continuous fir t and econd part al derivatives and satisfying Laplace equation in a neighborhood of a point is called harmonic at that point If a plane piece of tinfoil has its edge kept at a temperature which varies from point to p int but does not change with time and if the flow of heat in the tinfoil is steady (that i independent of the time) the temperature $u(x\,y)$ at interi r point of the f il is harmonic Likewi e I aplace s equa tion d minate the flow of electricity (the p tential is similarly harmonic) and the flow f any incom pre il le fluid

Two dimensional relations If $f(z) = u(x\,y) + iv(x\,y)$ is an analytic function $u(x\,y)$ and $v(x\,y)$ are onjugate functi ns and are harmonic (*see* COMPLFX NUMBFRS AND COMPLEX VARIABLES) Conver ely if $u(x\,y)$ i harmonic in a simply con nected region D one may et

$$v(x\,y) = \int_{(\ )}^{(\ )} \left(-\frac{\partial u}{\partial y} dx + \frac{\partial u}{\partial x} dy \right)$$

wher $(x\ y)$ i fixe l in D an l $(x\,y)$ arl itrary in D It follow fr m Creen the rem tl at tl e integral o er a path in D i in lependent of the path so $v(x\,y)$ s uniqu ely defin d tl ro igl out D the func ti ns $u(x\,y)$ and $v(x\,y)$ r conjugate in D and $f(z) = u + iv$ i analytic tl ere Under the e c n dition let C n w l a r gular Jordan curve in D if len t the int r r n rmal of C the e u ati n $\partial u/\partial n = -\partial v/\partial s$ f llow fr m the Cau hy Riemann quation wl en e

$$\int_C \frac{\partial}{\partial n} ds = -\int_C \frac{\partial}{\partial s} d = -v(x\,y)\Big|_C = 0$$

l u n $\phi(t)$ f m th er ting f ct n $f(s)$ Thi e pecl ll tru wh n tal les a u a a lalle r m deq te Any p es l $\phi(t)$ i t rm f $f(\ )$ i lled an in n f rm la (se INTEGRAL T A FORM) Ma y a kn wn Th la al e t

$$\phi(t) \quad \frac{1}{\pi i}\int_{-\infty}^{\infty} f(\ )e^{\ } d \qquad 0 < t < \infty \qquad (1)$$

ll the ntegr t i l ng n l e $\sigma =$ f tl compl s pla e wh h the nteg al (1) ges absol t ly A th r wh l mpl y th r l bl nl i

$$\phi(t) = \lim_{k\to\infty} \frac{(-1)^k}{k!} f^{(k)} \left(\frac{k}{t}\right)\left(\frac{k}{t}\right)^{k+1} \qquad 0 < t < \infty \qquad (5)$$

Here $f^{k}(\ )$ m an the kth d r ati f $f(x)$ Equ ti (5) I ll trated l th mpl A ω F r th t p $f^{k}(x)$ e ily mp ted and Eq (5) bec m

$$e^{at} = \lim_{k\to\infty}\left(1 - \frac{at}{k}\right)^{-k}$$

famil at result l l l

Generalizations Cert g n r l zat n of Eq (1) ar n f qu nt Th t n f rm

$$f(\ ) = \int_{-\infty}^{\infty} e^{-\ } \phi(t)\, dt \qquad (6)$$

t lled th b l t ral Lapl e t f rm A f till p ded by Eq (4) wh h n w h ld f $-\infty < t < \infty$ If n set $= iy$ Eq (6) the result

$$g(y) = f(iy) = \int_{-\infty}^{\infty} - \ \phi(t)\, dt$$

This equ t d fi es $g(y)$ the F r t a f rm f $\phi(t)$ Th t the Lapl e t f rm (6) if d ed l g gl l be mes F n t f m. By tt g $= 0$ and $s = y$ f r m la (4) bt

$$\phi(\ ) = \frac{1}{2\pi}\int_{-\infty}^{\infty} f(\ )e^{\ }\, d \ = \frac{1}{\pi}\int_{-\infty}^{\infty} g(y) \quad dy$$

th l l f th F n tr f rm

A th g r l zat of Eq (1) i th La pl St ltjes nt g l

$$f(\ ) = \int^{\infty} - \ d\alpha(t) \qquad (7)$$

wh e n w the i gr l St ltj tegr l w th esp t t th t g at f t n $\alpha(t)$ If $\alpha(t)$ h d at e $\phi(t)$ th tegr l (7) b mes (1) On the th b nd l $\alpha(t)$ t p-fu t Eq (7) ed t Di ll t ies

$$f(\ ) - \sum^{\infty} \quad - \ $$

t pe f l gr t mport n t al t numb theory

It m t t b ppo ed that o m y hoo $\phi(t)$ o $f(\ )$ b t l Fq (1) nd p t t m t t t F x mpl f $\phi(t) =$ the t gr l (1) d ges f all s d $\sigma = +\infty$ Aga

if $f(s) = s$ n c rresp nd ng d t mi ng fu t n $\phi(t)$ xi t n at i l n tl at g rating f t n m t appr ach limit a $s \to +\infty$ l ng th r al i H n e it i l l import t to kn w wh t f m t $\phi(t)$ and $f(s)$ may be u ed in Fq (1) S f r a $\phi(t)$ er ned tl p l l m c mpl t ly sol ed l y tl f rm il with $\sigma > 0$

$$\sigma = \overline{\lim_{t\to\infty}} \frac{l\ g\ |\phi(t)|}{t}$$

Tl tf r p ll m ha been part all sl ed l y r p res ntati then m f r i t gr l tr f m ne triki g ampl f wh h i pres ted lel w

A f n t $f(\ )$ f th r al ti ll s i ail t be mpl t ly m t n $< s < \infty$ if and l f

$$f(s) \geq 0 \quad f'(s) \leq 0 \quad f''(s) \geq 0$$
$$f'''(s) \leq 0 \qquad (< s < \infty)$$

F mples r $f(\ ) = 1$ $f(s) = 1/(-a)$ a d $f(s) =$ A theor m f S B r t tates that $f(\ )$ ha e p ese tati n (7) c n g g f r $>$ d with i t g t r f t $\alpha(t)$ der g if a d nly if $f(\ )$ mpl tely m t n f r $a <$ $< \infty$ F r e mpl if $f(\ ) = 1$ th n $\alpha(t) = 1$ $t > 0$ $\alpha(0) = 0$ if $f(s) = 1/(-a)$ th n $\phi(t) =$ e^{at} and $\alpha(t) = (e^{\ } - 1)/$ if $f(s) = e^{\ }$ $\alpha(t) =$ 0 f r $0 < t < 1$ d $\alpha(t) = 1$ f r $1 < t < \infty$ In ea h c $\alpha(t)$ decr a pred ted l y B rn t theo m Tl esult i p rt ul ly re m rkabl becau th m r ign f the rres v der ati es l f ti n n th r al xi d t m n t nly it h l m ph h ra t r (pr pe ty ll bo) in half pl e but also it rep esent ti th f rm f Fq (7) [D V W]

Bibl g phy A Erd ly (ed) *Tabl s f Int g al T nsf ms* l l 19-4 l Lapla *Th o i nalyt q d b b l tes* 1820 D V W d d *Th L pl T sf m* 1941

Laplacian

Th d ff r t l p r t r $\partial /\partial \ + \partial /\partial y + \partial /\partial$ t wh h the ymbol d t th al les f ect gul tes a oordi at y tem The Lapl n freq tly den ted by th mbol ∇ (r l d l q ar) n a rd c w th the fa t that th Lapl f ala f ct n $S(\ y\ )$ i th d g e of th gr d e t f S th t

$$S/\partial \ + \partial S/\partial y + \partial S/\partial z = \nabla \cdot (\nabla S)$$

The Lapl e pe tor n l ed i som f the m t fu dam t l q t n f m th m t al phy i mely Lapl q ti n ∇ P so q t o u w q t n (th e l lect ty a d m g et m eou d vibr t n th Sch od ng r q t f q a tum mech n cs) th h t fl w d d ff ty q t S CALCULUS OF VECTO S GAUSS THEOREM GRAD ENT OF A SCALAR GR EN THEORE [H V C.]

Irrotational motion implies that the fluid particles translate without rotation (like the cars on a ferris wheel) and is stated mathematically by saying curl $\mathbf{v} = 0$ where $\mathbf{v} = \mathbf{v}(\mathbf{r}, t)$ is the velocity vector, $\mathbf{r}$ is the position vector of a particular point in the fluid flow, and t is the time. If the fluid motion is at any time irrotational it will stay irrotational (*see* KELVIN'S CIRCULATION THEOREM). Thus any motion starting from rest will be irrotational. If curl $\mathbf{v} = 0$ then $\mathbf{v}$ may be written as grad ϕ because curl (grad ϕ) is identically zero. For an incompressible fluid the continuity equation (*see* FLUID FLOW PRINCIPLES) is div $\mathbf{v} = 0$; hence combining this relation with irrotationality gives Laplace's equation div (grad ϕ) = 0.

The velocity field $\mathbf{v}(\mathbf{r}, t)$ in a certain region is determined by Laplace's equation with a boundary condition given on the entire surface surrounding the region. The two most common boundary conditions are those at a solid surface and at a free surface. At a solid surface the fluid velocity normal to the surface must match the velocity of the surface normal to itself, $\mathbf{v} \cdot \mathbf{n} = \mathbf{v}_s \cdot \mathbf{n}$; that is, $\partial\phi/\partial n = \mathbf{v}_s \cdot \mathbf{n}$ is given on the boundary. At a free surface, such as one occurring between two fluids of different density, the pressure must be continuous; this boundary condition in general involves the use of the nonstationary Bernoulli equation and usually leads to wave motion. *See* BERNOULLI'S THEOREM; WAVE MOTION IN FLUIDS. [A.E.BR.]

Laplace transform

An integral transform extensively used by P. S. Laplace in the theory of probability. In simplest form it is

$$f(s) = \int_0^\infty e^{-st}\phi(t)\,dt \qquad (1)$$

It is thought of as transforming the *determining function* $\phi(t)$ into the *generating function* $f(s)$. The variable t is real; the variable s may be real or complex, $s = \sigma + i\tau$. As an example, if $\phi(t) = 1$, the integral converges for $\sigma > 0$, diverges for $\sigma \leqq 0$, and $f(s) = 1/s$.

The Laplace transform is used for the solution of differential and difference equations, for the evaluation of definite integrals, and in many branches of abstract mathematics (functional analysis, operational calculus, and analytic number theory).

Method. Extensive tables of Laplace transforms exist, and these are used as any table of integrals. To illustrate how a differential equation may be solved, two excerpts from such a table can be used:

$$\begin{array}{lll} \text{A} & f(s) = 1/(s-a) & \phi(t) = e^{at} \\ \text{B} & f(s) = 1/(s^2+1) & \phi(t) = \sin t \end{array}$$

Suppose it is required to find a solution $y(t)$ of

$$y''(t) + y(t) = 2e^t \qquad \left(y'' = \frac{d^2y}{dt^2},\ y' = \frac{dy}{dt}\right) \qquad (2)$$

such that $y(0) = 1$, $y'(0) = 2$. Denote the Laplace transform of the unknown function $y(t)$ by $Y(s)$. Integration by parts gives

$$\begin{aligned}\int_0^\infty e^{-st} y''(t)\,dt &= -y'(0) - y(0)s + s^2\int_0^\infty e^{-st} y(t)\,dt \\ &= -2 - s + s^2 Y(s)\end{aligned}$$

on the assumption that the integrated part is zero at $t = \infty$. Applying the Laplace transform to Eq. (2) and using A for the right-hand side, one obtains

$$-2 - s + s^2 Y(s) + Y(s) = \frac{2}{s-1}$$

The differential equation has become an algebraic one whose solution is

$$Y(s) = \frac{1}{s-1} + \frac{1}{s^2+1} \qquad (3)$$

However, a further use of the table shows that the Laplace transform of $y(t) = e^t + \sin t$ is precisely the right-hand side of Eq. (3). Assuming uniqueness, one has thus obtained the required solution. Because its properties can be checked directly, the unproved assumptions need not be verified.

This example illustrates the general method. The unknown function is taken as the determining function and the Laplace transform is applied to the differential (or difference) equation. There results an equation with the generating function as unknown, and this must be solved. Finally the determining function must be determined from the generating function, either from tables or by use of an inversion formula. In general, if the original differential equation is partial in any number of independent variables, one application of the Laplace transform reduces the number of these variables by one. If the equation was ordinary (one independent variable), the transformed equation is algebraic, as in the above example.

Properties. Here are the fundamental properties of the Laplace transform.

I. There exists a number σ_c (perhaps $+\infty$ or $-\infty$), called the abscissa of convergence, such that the integral in Eq. (1) converges for $\sigma > \sigma_c$, diverges for $\sigma < \sigma_c$. That is, the region of convergence is a half plane (a half line if s is real).

II. The generating function is holomorphic for $\sigma > \sigma_c$.

III. The determining function is uniquely determined by the generating function. (Ambiguity is possible only on sets of measure zero.)

IV. The product of two generating functions is in general a generating function. Thus if Eq. (1) holds for two pairs of functions $f_1(s)$, $\phi_1(t)$ and $f_2(s)$, $\phi_2(t)$, then the product $f_1(s)f_2(s)$ is the transform of the convolution

$$\phi_1(t) * \phi_2(t) = \int_0^t \phi_1(u)\phi_2(t-u)\,du$$

As was evident in the above example, it is very important to be able to determine the determining

Th d w l k St H m g l gth t 11 t (From E L P lm F ldb k f N t of H st ry McG -H ll 1949)

nt th Un ted St tes m ny t me d n t tro d t n rv ed Lo g l la d f m re tha 20 yea At p t th ly kn wn ol ny f l k in N rth Am t s n N n l l nd B t h Col mb

Horned lark Thi b d *E m ph la lpe tris* of th family Alaud da r rep e nted l y um n bspec s It h pe h p th w d t n tural r nge of y so gbird b ng f u d i Eu p A N rth Afric and So th Ame s well i North Am ri It i a d k br wn t s ndy col red b d th pa r f m ll bl k ea t ft The f h d heek tr p a d b d tl l r a t are lso bl k The thro t a e f m wh t t y ll w Th ut t l feath are bla k th be t fi ld mark fl ght The h d la k i a b d f the pe try d pp ently eq me bar g d t th D g th m t g eason th mal f q tly ng ge in em k ble rti cal fl ght, ng n a it cl mb and te m i t g i a breath t k g d e t pull g nruffled l d o ock h fo ts m te H ed l rk g gate i l g flock d ring th w t S e PASSERIFORMES Robi [J D B]

Larmor precession

A p eces ion f the m t of harged part le i a m g tic field (PRECESSIO) The La m theo m (J Larm 1897) t t that f l t n m ng ngl tr l fi ld f f r th mot o in a u f rm magn t fi ld H t fi t rd i H th am a pos ble m t n i th ab e f H pt f the pe po t f mm p e s of g l r f q n y

$$= - H/2m \qquad (1)$$

he e /c the magn t de f th l t n ha ge l t m gn t u t d m th el t ic m The f qu y ω_L i all d th Larm f q n y a d t n merically equal t r tim 1 10 Me p r er ted

The Larm r theor m i d rived in num rou text F r tl e pec l ca f an elect n movi g in cir lar l t f radiu r al n a f xed nucl i w th H p l ed n rm l t the plane f th orbit the d ri ati i f ll w tl e trip tal f r h ldi g tl lectr n in tl at m i t j l $n \omega r$ a l s tle im f th Co l mb f rce Z / and th Lor ntz forc $-(/c)\omega rH$ Tl ref r

$$\omega = \pm[(H/m)^2 + (Ze^2/mr^3)]^{1/2} - (H/m)$$
$$= \pm(\omega_L^2 + \omega_0^2)^{1/2} + \omega_L \qquad ( )$$

wh ω_0 i tl ngular frequ ncy in the al ence of H H $\omega_0 \gg \omega_L$ (boun l electron and f r t r l r in H) th appro im te g lar frequ y

$$\omega = \pm\omega_0 + \omega_L \qquad (3)$$

whi l i tl Larm r theor m F a free r t n l u d elect (n C l mb for) tl appr xi m t l ak d wn l t d rect sol ti n l the eq u t n i l ing $m\omega r$ a d the l re tz f rce ld $\omega = - H$ me Th i twi e tl Larm r fre q e cy nd i called tl e y l tr n frequ ncy S E RTIEF AC ELERATOR

l t ti g tl Larm ther em u wa made f tl pl a po ble m ti If H i applied ff ntly l wly it an be g ed tl at tl e m ti n i tl me a in th al nc f H except f r the t p it m f tl Larm r preces H wever dd n ppl ti n f H m y ha g f exam pl la rl t int n ell ptic l n

F r a important ppl cat n f th Larm r theor m s DIAMAG ETI M ls ELECTRO TOTI N IN VACUU [E A F K]

B bl g aphy G Joo *Th o t l Phys s* 3d d 1958

Larnite

A rar n e l at m n ral w th mpo ti Ca_2SiO_4 whi h w r g ally de cril ed in 1929 f m Scawt Hill C ty Antr m Ir l nd Well f rmed t l h tl n l rved l ut tl e pr nc of tw mutu lly r e p dicula l a ges w th poly nth ti tw n g p r llel t n of th m nd c te m n l symm try Three art fi l cal m J t s f thi same c mp t n ar des g ated a α β nd γ Lar t prob bly re po d t o Ca_2SO_4 T n f rmat n t the γ pha may l e p o du d by heating by hock At Sca t H ll larn te i tim tely a ated with pur it mel l te m w t d p l z a l m t onta t z n It ha l be d cr b d fr m Cre tm e n ar H r d Cal f a S SILICATE MI ERALS [C.S HU]

Larvacea

A la s f the ubphyl m Tun ata con ting of m n t pla kto c n m l wh h the ta l w th d r al n rv o d a d n tochord p r st thr ugh t l fe Two g ll l t r omm ly pre ent but n t m lack ng Th ep d m of the te ior r g ec t s gelat n tun wh ch i m

Lapping

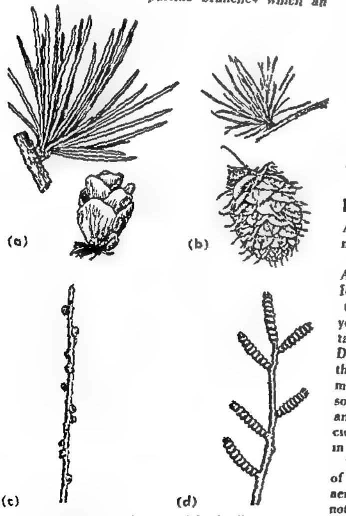
A precision abrading process u ed to bring a sur face to a desired state of refinement or dimen ional tolerance by removal of an extremely small amount of material Lapping is accomplished by abrading a surface with a fine abrasive grit rubbed about it in a random manner Usually less than 0 0005 in of stock is removed

A loose unbonded grit is used It is traver ed about with a mating piece or lap of a somewhat softer material than the workpiece The unbonded grit is mixed with a vehicle such as oil grease or soap and water compound When a bonded grit is used it may be in the form of a bonded abrasive lap or a charged lap such as cast iron or copper with the lapping compound embedded in it In some cases abra ive covered paper laps are used

Although some lapping is done by hand most production work is done on a lapping machine Various type of machines are designed for work on flat cylindrical and spherical urfaces *See* GRINDING MACHINING OPERATIONS [A T]

Larch

A genus *Larix* of the pine family with deciduous needles and hort spurlike branches which an nually bear a crown of needles Th cones are ma and persi tent varying by pecies in ize number and form of the cone scales The tamarack *L laricina* al o called hackmatack is a native pecie has erect narrowly pyramidal habit and grow in wet and moi t oil in the northea tern Unite States west to the Lake state and acro Canad to Alaska The cones are ½–¾ in long Th toug resinous wood is durable in contact with the oi and is used for railroad ties posts sill and boats Other u es include the manufacture of excel ior cabinet work interior fini h and utility pole



(a) Tamarack La i la cina (USDA) (b) We te n larch L occ d ntal s (USDA) (c) E opean la ch L dec dua (d) Golden larch Pseudolar am b l s (A H G a es Illustrat d G de to Tr es a d Sh ub Ha pe 1956)

The western larch *L occidentalis* the mo t im portant and large t of all the specie grows in the northwestern United States and outhea tern Brit ish Columbia The cones of this pecie are larger 1–1½ in long with bracts growing out beyond the cone cales The trunk is tall and erect ometime attaining a height of 200 ft and a diameter of 6–8 ft The western larch has an e timated tand of 20 000 000 000–30 000 000 000 board ft mo tly in the national forests The annual production of the lumber u ually ranges from 200 000 000 to 300 000 000 board ft More than one half of the producti n comes from Montana the remaind r from Idaho Wa hington and Oregon

The European larch *L decidua* has cone about twice the ize of tho e of the tamarack and 40–50 scales to a cone whereas tamarack has only 12 15 The European larch does l etter in drier oil and i the species usually planted in parks and private grounds

Golden larch *Pseudolarix amabilis* from China is occasionally cultivated Its leave al o d cidu ou are golden yellow in the fall The cone cales fall off one by one leaving the central axis of the cone on the tree *See* FOREST AND FORESTRY TREE. [A H G]

Lark

Any of a group of birds the be t known are the m adowlark the skylark and the horned lark

Meadowlark This is either of two pecies of American bird of the genus *Sturnella* family Icteridae The meadowlark is larger than a robin t utly built brown treaked al ove with a l right yellow breast cros ed by a black bib The outer tail feathers are white and are prominent in flight Darker than the western meadowlark *S neglecta* the eastern meadowlark *S magna* is more com monly di tingui hed by song than by color The song of the we tern pecies i di tinctly different and more melodious than that of the ea tern spe cie The range of the two pecies broadly overlap in the Mi i ippi Valley

Skylark A Europ an songbird *Alauda arve si* of the family Alaudidae i famed for its parkling aerial ong The skylark is a dull l r wn b ird not prominently marked but readily di tingui hed from the h rned lark by the pre ence of white uter tail feath rs Like oth er larks it i a l ird of the op en l arren ground and i terre trial in it hal it

The natural range of th skylark include m t of Eur pe and N rth Afri introd ced

Latent image

An in i ble imag p oduced by a ph s l or ch m al effect f light on the di id l ery tal (u u ally l r hal d) f phot g aphi emul ion The im g n be r ndered v ble by the proce kn wn a d vel pment Fo detail f lat nt image f rma n a d de elopme t s e PHOTOGRAPHY PHOTOLYSIS (PHOTOCHEMISTRY) [K W P]

Laterite

Th am g e by F B h nan (180) to the ir n rich th ring produ t of l alt in s thern In dia. The t rm t ow u ed a e mp ti nal sense f w the ng prod t e mpo ed pr cip lly f th o des a d hydrous o ides of r n al im n im ita m d manga es Ir n r h r f rr gi l r rite t l g ly h mat te Fe O and goetl t HFeO d may be an re f iron a d ckel (Cub New Caled a) Alumi u late ite is com posed f g bb te d boehm t a d i th pr i pal re of lum n m (s e BAUXITE) Cl y m n al f the k ol n gr p are typ lly a sociated with a d r g t ally r l ted to l te te Lat it ang from soft, earthy porou mat i l t ha d dense rock Concret ry forms f ryi g ze d h pe c mm ly are dev l ped Th l r de pend on the o tent f i n x de nd ra g from b te t d rk ed r b w e mm l a te gated S CLAY MINERALS KAOLINITE WEATHERING PROCE

Origin Lat rite i f rm d by w athe ng u d r co di th t l ad t the em l f lt a lkal es, d alk l e e rth Th res lt ng tr n of i a d l m um o des h pl d f f e t at l te t zat from t mp rate l mate weatheri g wh ch the d prod ct i la gel l y min ral (h dro lum m s l c tes) F rly w k i f om t mpe ate r g o e n d d f te t zat n as pr f n l l ach g (des l t) n stag b yo d rd ry kaol zat n tud es t tr p l gions howe h w th t w athering of alk l e l c t m y y ld g bb it d ectly w th t p g th o gh nt rmed t f y tag

In estigat in many pa t f the w ld tr ertai g et f t A t pical t bt op l limate w h h gh temp atu d b ndant a f ll, se so al at l a t w th p d f m k d dry es f dam t l Rel f ffic ent to n u good dra g eq t l t t ls a p rm bl nd d t d by h t wa h l k l y or tale. Al m u l t it f m b th w t table a d may g de t l y d pth It m y be f nd n h ll d w ll-d d l p b t th du l d pos ts dj e t alley lly k lin

Parent materials Th p r nt m t l t ol gr tly fl en th e mp t n f l t te wh h ma be dev l ped Ir m ri ty f ign u m tam phic d ed m t ry r k l h k (p d tu) ld l m n r k f t) p od bau t wh s de te b lt g t rmed at n od t Commo ly tex tural d tru tural f t e f the pare t mat ri l are pres rv d and th m re re i t nt insol ble m r l rema n

Mat re l t rite oil l ck f rtility f r m t sy t m f agr ulture Sa na r parkl ke gr land ar typical n laterit Clay n l t rit i f und beneath r nf re t and jungl veg tat n S e VEGETATION ZONE [C]

Bibl g aphy S e BAUXITE

Lathe

A machine f r the r m l f m tal fr m a w rk pi ly gripping it s curely in a l olding dev a d r t ting it und r pow r again t a itabl cutt g tool The tool m y be m ed ra lially r l git d n lly in re pect t the t rn ng x f th w rkpie ther ma ually l atta hed pow r f rm sel a n pl res a l r latel n tr c h ped w kp eces a well a tr l d r an be turned n a l th M h ning p s h a fa ing l i g and thr ad ng whi h re v i t n of the tur ing proce an al le per f med n a l th

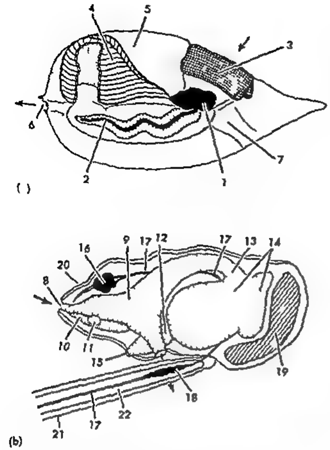
Turn g quipme t may be cla ed a be ng e ther l th h riz tal r rt al type ref rr ng t th turni g ax f the w rkp ee in th ma h Th l a eng ne lath i p im r ly a m n ally per ted ma h Fill g th g p bet ee th n gin lath e a d f lly a t matic tu n ng eq ipm t i th tur t lath Fa t nd l t ited t h gh q ntity produ ti n i th aut m t crew ma h

Engine lathe The tile engi e lathe r nge i i nd design fr m mall be ch and peed l the t l ge floor t p The w kp ec m y be held between tapered c nt s a l r tated w th the p we pi dle l y me f a clampi g devi r it ma be h ld i a h ck e n fixed to a r t ting pl te Wh n th w rk wu g bet r cente th tail tock wl h h l l the tail n ry tap red ter i l mped firml in pla e Long w kp eces may b pp ted in th m ddle by eith r a te dy r t mech n lly dri e f ll w re t whi h m s w th th cutti g tool

Th ngle po t tool held in a tool p t r bl k whi h upp ted n a cr lide and car iag Th t l may b m ed r d ally o l ng t din lly in relat n t the w rkpi e

Angula ut ar p bl and l ng it dinal ta p s m y be t by off ett ng th tail tock o b dj tm t of a tap r atta hm t n th r ar of the lathe whi h a tu t the c l d

Turret lathe Th t l t ck of the ng lath pla ed w th m lt ded d x ng tool h ld r t rret de gned t ld ever l tool th m l b m g at rr t l th Th s ngle to l t a d mp nd s ally repla ed by a fou p t de i g tool t P w cut m y b t ken f m both of th t ol m ti g th r p d du lly or imultan Tu ret lath a mad rti l m d l w ll h z ntal H zontal t r et l th e cl ed a th b r r h ck g m hi r f r g t th m n

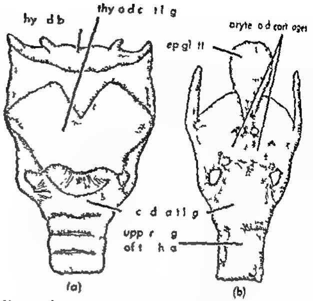


Larvacea (a) A larvacean O kopleu a d o ca in t house 1 body of animal 2 ta l 3 wate ntake f lter 4 food concentrat g apparatus 5 gelatinou material of house 6 water outlet 7 emergency e t (b) body and anter o tail eg on of O kopl ra d o a 8 Oral aperture 9 pharynx 10 endostyl 11 buccal gland 12 g ll sl t 13 esophagus 14 lobes of stomach 15 a us 16 dorsal ga gl on 17 dorsal ne e cord 18 caudal ganglion 19 go ads 20 o koplast epithel um which sec etes the hous 21 ta l 22 otocho d

posed of polysaccharides bearing amino groups but contains no cellulose In some sp cies this tunic is highly complex and encases the whole body in a house equipped with chambers and trainer which enables the inhabitant to filter and concentrate the finest of plankton from the sea About 60 species are known *Oikopleura* and *Fritillaria* are the largest genera *See* TUNICATA [D P A]

Larynx

In man the voice box The signet shap d cricoid cartilage forms the base which rests on the trachea The paired thyroid cartilages which form the prominent Adam s apple in front lie above the cricoid Po teriorly there are paired pivoting cartilage the arytenoids Each is pyramid haped and acts as the movable posterior attachment for the vocal cord and the laryngeal mu cles that regulat the cord Two other mall paired cartilage the cunei form and the corniculate also lie behind the thy roids The lid of the box is the epiglotti a l af shaped cartilage with its stem in erted into the thyroid notch *See* CARTILAGE



Human laryngeal cartilages and l gaments (a) F o t view (b) Back v ew (After Sappey from J Sym ngto ed Qua s Elements of Anatomy vol 2 pt 2 Lo g mans G een 1914)

The larynx is a derivative of the primitive gill bar system of vertebrate Its original function is to act as a protective phincter at the air pa sage a function still retained in lower animal Only in higher vertebrates has phonation been acquired it i al most limited to mammals since in birds the sound is produced lower in the airway *See* SPEECH *See also* LARYNX DISORDERS THYROID GLAND

[F G ST]

Larynx disorders

Diseases of the larynx manifest them elves b hoarseness and by stridor a form of noisy breath ing caused by localized narrowing in the larynx or trachea

Laryngitis is an inflammation of the mucou membrane of the larynx always as ociated with hoarsene s It frequently occurs with commor colds and as a complication of other inflammatory diseases of the upper respiratory sy tem In diph theria th formation of a membrane of fibrin leukocytes destroyed tissue and l acteria can cau e severe respiratory diffi ulties which might demand tracheotomy The development of chronic laryngitis is fa ored by a chr ni irritation uch a that cau ed by smoking

Hoar ene s is also a manife tati n of paraly i of the recurrent laryngeal nerve of the vagu (see NERVOUS SYSTEM) whicl i ea ily lamaged upon surgical rem val of a g it r

Benign tumors of the larynx occur in the yo inger age group A tumorlike formati n of the ocal cord kn wn as ing r n de often ac int f r the hoar ene of pe ple who al u e the vo c Cancer of the larynx i n t unc mmon in man l t is frequently of a sl wly growing typ and th out l k is often good The highe t inci lence i m mal over 60 [F W F]

Latent image

ible im ge produ ed by phy ical or ch m al effect of l ght n the indi idual cry tal (u ly sil e h l d) of ph t gr phic em l i n Th e can be re dered i ble by th pr es known dev l pm nt Fo deta ls f latent imag f rm n a d devel pm t se PHOTOGRAPHY PHO-LYSIS (PHOTOCHEMISTRY) [K W F]

Laterite

i ame g e by F Buch nan (1807) t th r h th r g p od t of b alt n uth rn In The t rm i n w ed in e mpo ti l se f athen g p od ct c mpo ed pri cip lly th des a d hyd ou ox des f ir l m num a m a d m ng ese I h r f rigin u tent l rgel hemat t Fe_2O_3 nd goeth t FeO d may be an re of ir and n kel Cuba, New Caledo a) Al min u l te te i com sed of gibbs t a d boehm t a d i th pr c l e of lumi um (se BAUXITE) Cl y m ne l th k l n g p a e typ cally sociated with ld r g net cally r lated t later t Lat it f om soft, arthy po mat ial hard me ock Co cret ary f rm of ary g ze d h pe c mm nly a e d eloped Th col r d nd on th co te t of ir n des a d r ng om wh t t d k red b w mm nly a ted. S CLAY MINERALS KAOLI ITE W ATHER G PROCES

Origin Late it i f rm d by we thering nder d t that lead t the rem al f l a k l s nd alk l e rth The res lt g n t s f r d al m n m ides h r l d f rentu te l te t zat f m temper te el mate the g wh h th e d prod t i la g l clay in al (h d lumi m l cat) Early k s f m i mp ate reg o d ed l t i zat n s pr fou d l h g (d l t) n a g beyo d d n ry ka h zat n St d es in p l regi a h wev sh w that we thern g of lk l e l ates may y ld g bb t d r tly w th ut p i g th ough r rmed te l y tag In est gat ma y p rt f the w ld tres rla n g t e f t A t op l t ht p l lim te w h h gh temp t d b nd t a n ll aso f t le t w th per od f ma k l ry t f nd ment l R l f uffi t t en te ood d a g t eq t l t t l e m bl nd d t d by h et w h l k l y h l Al m u l terit f rm bov the t tabl nd ma g ad to l y d pth ft m y h r d l d pos t i dja nt lley ally k l

Parent materials Th pa e t m t al nt l gr tly fl en es th mpos t n f l t rit h h m y be dev l ped f m ety f ig eo n tam rphic a d ed m ntary ock I n t h ock (p d t t) y ld n l m nou rock t) p od l s wh e des t lt g term d t p od ts Comm ly tex tural and tr ctural feat res f th par nt material are preserved an l th m r rest t t in lul l m n er l r m in

Mature l terit c soil la k fertility f r m t y t m of gricultur an r park l ke gr land ar typ al n lat rite Clay n t l terit f f nd bene th r inf e t an f jungl v g tati n S VEGETATION ZO E [C]

Bibl graphy Se BAUXITE

Lathe

A ma h n f th r m al f met l fr m a w rk piec by gripping it ecur ly in a h ld ng dev e and r tat g it und pow r gain t a itabl cutting too l Th tool may be m ved rad ally l g t l lly i respect to th turn ng f th w rkpiec eith r m nually r by att hed power F m h a pl es n l r l ted c n ntr l aped w rkpieces a w ll a tru yl nd r ca be turn d n a lath Ma h ni g operati h f cing boring a d th r ad ng whi h ar va ati f th t r g p ices a al be per f rmed n a l th

Tur ing eq pm nt may be cl ed being e th f th h ri ont l r ti al type r ferr ng t th t rn g a f th w rkp in th ma h n Th ba ic engi l th i pr m ily a manu lly perated ma hi Filli g th gap between th n g n l th e and f lly t mati turn g eq ipm nt i th turr t lath Fa t d best s it d t h gh q nt ty pr du t n i the a t m t ic ew ma hin

Engine lathe The er t le eng ne lathe range i ze d des gn f m mall bench and peed lathes t l g floo type The w kp ec may be h ld betwe n tape ed ter and r tated w th th power pindl by m f a clampi g devi it may l h ld a h ck r even f ed t a r t g plat Wh n th w rk i wing betwee nte th ta l tock wh h hold the tat ary t pered nt r lamped f rmly n pla Lo g w kp e s m y be pported n th m ddl l y e the a t ady rest r mecha ally d i en f ll w rest wh h m w th th cutti g tool

The gl po t tool i held in a tool po t or block wh ch i s pport d ro l de and c r r ag The tool may be m ed ad ally o l ng tu d n lly r elat t the wo kp

A gula ut are po bl a d l git d al ta p a m y be c t by ff ett g the ta l tock o l y dj tm t f a t per tt hment n the r ar of th l th wh h act ates th os l de

Turret lathe The ta l tock f th eng n lath n be r pl ced w th a m lt ded i d ing tool h ld r t rr t des gned to h ld es al tool the m h be m g t rr t l the The ngl tool post d mpo d u lly repl c d by a f ur post nd g tool post P w ut m y be tak f m both f these tool m u t ng th r n d d ally m lta eo ly Turr t l the are m d rt al mod l w ll h izo tal.

H zontal t et lath a cl d a th Bar h k g m h nes f rri g to th m nner

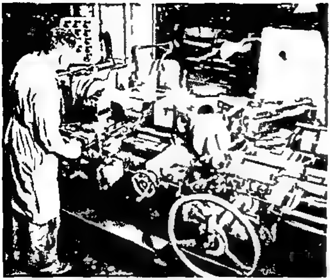


Fig 1 Saddl type tur et lathe (Jo es and Lamson Mach Co)

in which the workpiece i held The headstock of the bar machine i con tructed so that bar stock may be slid through it and the collet on line with the turning axis of the lathe The collet closes holding the piece firmly Chucking type machines grasp a unit size workpiece in a chuck or jawed de vice Chucking devices permit work of relatively large diameters to be machined

Horizontal machine may be further classed as being either of the ram or saddle type a designa tion referring to the manner in which the turret is mounted on the machine On the ram machine the turret i mounted on a ram or slide which rides on a saddle When the turret i indexed for successive operation the saddle acts as a guide for the ram in its trokes to and from the work On the saddle type machine de igned without a ram the turret mount directly on the saddle which lides on the bedways of the lathe (Fig 1) Ram type lathes with their short turret travel are generally of lighter construction than the saddle type Exce ive overhang of the ram redu es tool rigidity Fast in operation they perform be t on mall diameter work and light chucking job The rigid construc tion and the longer troke of the addle type lathe enable it to handle both longer and hea ier bar and chuck work than the ram type machine

The vertical turret lathe imilar in principle to the horiz ntal machine i capable of handling hea ier and bulkier workpieces The vertical ma chine i con tructed with a rotary horiz ntal work table who diameter normally de ignate the ca pacity of the machine Machi table range from 30-74 in in diameter A cro rail m unted abo e the table carrie a turret which indexe in a verti cal plane with to ls that may be fed either acro or downward (Fig 2) The cro rail may al o carry ertical swiveling ram with a nonindexing tool holder which feed in a manner imilar to the turret Below the cro rail a side head with an in dexing tool holder is ometimes pro ided Th t l may be fed in h rizontally or m ved ertically

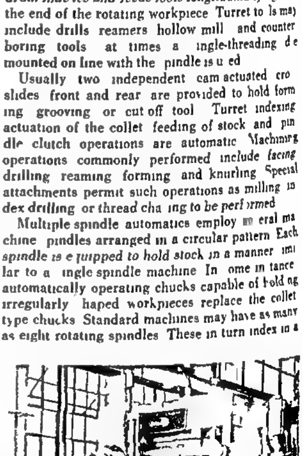
Tools may be operated simultaneou ly either man ually or by power

Automatic screw machines When a high pro duction rate of relatively small turned parts is re quired automatic screw machines are u ed The screw machine was originally developed from the lathe for the purpose of more economical manu facture of screws and bolts The name ha per sisted even though numerous partially or com pletely finished products are produced on them. Generally these machines are clas ified as ingle spindle or multiple spindle automatic The u ual machine is of the horizontal type

The single spindle machine is con tructed to feed bar stock through the hollow machine pindle and collet similar to a turret lathe When the bar meets a stop the collet closes on the piece The manner in which the cutting tools are held may vary Usually a small five or ix po ition turret or drum indexes and feeds tools longitudinally again t the end of the rotating workpiece Turret to ls may include drills reamers hollow mill and counter boring tools at times a ingle-threading d e mounted on line with the pindle is u ed

Usually two independent cam actuated cro slides front and rear are provided to hold form ing grooving or cut off tool Turret indexing actuation of the collet feeding of stock and pin dle clutch operations are automatic Machining operations commonly performed include facing drilling reaming forming and knurling Special attachments permit such operations as milling in dex drilling or thread cha ing to be perf rmed

Multiple spindle automatics employ se eral ma chine pindles arranged in a circular pattern Each spindle is e uipped to hold stock in a manner imi lar to a ingle spindle machine In ome in tance automatically operating chucks capable of hold ng irregularly haped workpieces replace the collet type chucks Standard machines may have as many as eight rotating spindles These in turn index in a



Fg 2 Ve t l t et l the (B ll d Compa y)

arm about a n nr t ting turret wh h l ld a et of utt g tool A a l pindl dex d pr gre ar d the a r r ece e m h g operat ns a e pe f rmed l th t r r t ools. S multa e ly tool l e ted m m o ti a pe f rm g ther espe t e pera th a w kp eces C lides n u ted at r ght angles t th pindl arry the m n groo g e t-off tool

Th t m f th l t pl th Th wan e l r u h pr g amm g a ti n a de g nd tool tr ng et th time req e l t pr d e fin hed p ec By d d ng l ng e t t tw m perat ns the ycl ng tim may l re duced M h perat perf rm d n th ma hi es e g erall th me a th e d n n ngl dle a t ma

M lt l m lt ple- pndl m h es f th m mat ma h k g t pe e n tr ted w th a m v a 16 p dl A h z tal r ilar t lle h lding the r t g chu k de e ind the ert l pndles w th a d ff r nt p at n le ng p f rmed t h t t n Th ma h e n tr i ted t b dl mu h large w kp eces tha h v tal a to ti m y mod l th peed feed and direct f r tat f r ea h p dl ml an m y b a ed f m p t n t the t Th p rm l el t n l the t feed and p ed f th p t n be p rfo med t h t t n S MACHINING O R TIONS [A T]

Latite

An ph n tic (t hly ry tall) r k f v l g ompo d h R l d plag ocl (ol goc) a d) a d lk l feld p a d e rthocl e) w th s bord nat q nt t f d k e l ed (mafi) m al (b tit mph bol pyr x e) Latt i m te les r t rm di t betw n t hyt d a de t Pl g l e d mi n t alk l f ld p a l ite b t bo d te t alk f ld p t a hyte A desit r e l ttl o no alkali f ld pa S TRACHYTE. [C.A C.A]

Latitude astronomical

Latit d det rm ed by t n m al b erv t on as d t ou hed fr m g g ph c l ti tud wh h th t h w o m p A tr n m l lat tud d t rm ed b th defin t on that th g l r alt t d f th h r n f th elest l pol d nt l w th th l t tud f th ob m The l t tud f th p l e t d by l rv g th me d n h t d f a lest l bje t who ed l t kn wn Th d by m u ng th a gl b t n th l e f ght a d ho iz nt l u f h h s tabl h d th by th bl h n l qu d fa p t l l d d lly z pe pe d u[z th d t n f g ty Th d ect l g u l ally h weve th det t b g all d d R t f the t l (Lo C TUDE AST O ICAL) A m p e t u r d v lu ly f m c m l b rv ti aid he d t t d by a f w h ded f t t m th n ml S e GE DE Y [G M C.]

Lattice (mathematics)

Latt tice y l l with p pert es f r l r anl n el r m l a gr p tl ry treat sm tr (see GROUP THEORY) A a g n r l t f Bool n al lr l tt e tl y w fr t app l ed r l l900 by R Ded k l t lg lr e mler tl r B t m r e m t m j r l a l f m tl mat es t f var a pe t f lg bra geom t y l f t n la alyt a w ll a f tt ry l m nt pr l bili ty (t wl l Bool n algebr l l al l been appl ed) lates f tl rs 1933 1938 See BOOLEAN ALGEBRA SET THEORY

Tl m st l a cept f l tt e tl ry that f a pa t l l r f a set S f l m nt x y B tl me t l n r l t n lly l n t l $\leq$ (r $\geq$) w tl tl f ll p pert es

(P1) $x \leq x$ for all $x \in S$

(P2) If $x \leq y$ l $y \leq x$ tl $x = y$

(P3) If $x \leq y$ l $y \leq$ tl n $x \leq$

If $\leq$ y pa t l r l ng f S, tl n it r rse l l $\geq$ l f ned l y tl t t nt

$$x \geq y \text{ if and only if } \leq \quad (1)$$

i l a pa t l r l f S Tl ly r f ed f ct p r l f ndam t l D l ty l rin y l wl l ful n m t e n ect n

Suppos f xampl th $x \cup y$ f tw l m t l f part all r l red t S l f ed by th n l t n

$$\leq x \cup y \qquad y \leq x \cup y \qquad (2)$$
$$\text{n l f } x \text{ } l \text{ } y \leq \text{ tl } x \cup y \leq \qquad (2')$$

(It sly h w tl t th at m t n l $x \cup y$) Th tl d l t p i c pl grest d f ng th meet n y l)

$$x \geq x \cap y \qquad y \geq x \cap y \qquad (3)$$
$$\text{a d f } x \geq \text{ a l } y \geq \text{ th n } x \cap y \geq \qquad (3')$$

n f h tl t tl e t m t n el n y

A l ttce l fi l a pa t ally o l l wh l ny t l m nt x and y h v meet $x \cap y$ d a j n $\cup y$ Thes l ty perat t fy f r ba d ti es

(L1) $\cap x = x \cup x = x$

(L2) $x \cap y = y \cap x$ a l $x \cup y = y \cup x$

(L3) $\cap (y \quad) = (\cap y) \cap$ n l $x \cup (y \cup \quad) = (\cup \quad) \cup$

(L4) $\cap (\cup y) = \cup (x \cap y) = x$

Th pe at n l u n ted w th tl rel $\leq$ l y th e d t that $x \leq y$ $x \cap y = x$ a l $x \cup = y$ th l nt t t m t Co ly f L n l l y t m w tl pe t o n l u t fy (L1) t (L4) f all x y tl n tl p ced l t n def $\leq$ a p t l rd r of L w th espe t t h h n and $\cup$ h th m d fi ed at Tl p pl was d ed l y C. S P (1880)

Kinds of lattices Th a many diff nt k nds fl t ce Th th al mbe s f n l tt f $\leq y$ g n t m ng Th s l tt mply d ed th th

(P4) Given x and y either $x \leqq y$ or $y \leqq x$ Any such simply ordered set (or chain) is a lattice in which $x \cup y$ is simply the larger of x and y and dually

Again the set J of positive integers forms a lattice if one lets $m \leqq n$ mean m divides n (usually denoted $m|n$) In this case $m \cap n = \gcd(m\ n)$ and $m \cup n = \text{lcm}(m\ n)$ Still again one can let Σ consist of all subsets S T of a fixed ensemble I and let $S \leqq T$ mean that every point in S is in T Then Σ is a lattice in which $S \cap T$ is the intersection of S and T *whereas $S \cup T$ is their union Actually Σ is a* Boolean algebra

In all the preceding lattices the distributive laws hold

(L6) $x \cap (y \cup z) = (x \cap y) \cup (x \cap z)$ and $x \cup (y \cap z)$ $= (x \cup y) \cap (x \cup z)$ for all x y

Such lattices are called distributive lattices Any chain is a distributive lattice so is any Boolean algebra More generally a ring of sets is defined as a family Φ of subsets of a fixed set I which contains with any S and T also their intersection $S \cap T$ and their union $S \cup T$ Then any ring of sets is a distributive lattice

It is obvious that each of the two identities of (L6) is dual to the other It is a curious fact that *in a lattice each also implies the other*

If G is any group then its subgroups form a lattice and its normal subgroups also form a lattice in both cases under inclusion The normal subgroups satisfy the (self dual) modular law

(L5) If $x \leqq$ then $x \cup (y \cap z) = (x \cup y) \cap$

In general lattices satisfying (L5) are called modular and every distributive lattice is modular

The lattice of all linear subspaces of the n dimensional vector space V (F) over any field (or division *ring) F is also a modular lattice usually called the* $(n-1)$ dimensional projective geometry $P_{n-1}(F)$ over F This lattice contains special elements 0 (the zero vector) and $I = V$ (F) (the whole space) such that

(P5) $0 \leqq x \leqq I$ for all x

Such special elements always exist in any lattice whose chains all have finite length But they need not exist in general for example they do not in the simply ordered set of real numbers

The lattice $P_{n-1}(F)$ is complemented in the sense that each subspace x has at least one complement x with the property that

(L7) $x \cap x = 0$ and $x \cup x$ I

Thus $P_{n-1}(F)$ is a complemented modular lattice Similarly it may be verified that the class of Boolean algebras is precisely the class of complemented distributive lattices This principle enables one to consider Boolean algebra as a branch of lattice theory

Lattices L containing few elements can be conveniently visualized by diagrams In these diagrams small circles represent elements of L a being higher than b whenever $a > b$ *A segment* is then drawn from a to b whenever $a > b$ but no x exists such that $a > x > b$ Any such diagram defines L up to isomorphism $a > b$ if and only if one can travel from a to b along a descending broken line Figures 1 5 are typical such diagrams

Such graphs often give useful information very simply For example let a finite lattice be called semimodular if any two elements a and b immediately above (covering) a given element c are also immediately under (covered by) another element $d = a \cup b$ This condition can easily be tested by inspection Dedekind showed that a finite lattice L was modular *if and only if it and its dual were both semimodular* For L to be distributive the extra condition of containing no subgraph such as that of Fig 2 is necessary and sufficient

Fig 1 The ordinal number 4

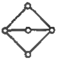


Fig 2 The projective line over the field J_2 of integers mod 2

Fig 3 The simplest nonmodular lattice

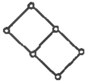


Fig 4 The lattice of divisors of 12 under divisibility

Fig 5 The Boolean algebra of order 8

Applications to algebra and geometry Lattices like groups and rings can be defined as abstract algebras that is as systems of elements combined by universally defined operations These operations may be unary binary or ternary In any such abstract algebra A the subalgebras form one (complete) lattice and the congruence relations form another

Though not many results are valid for abstract algebras in general it is known that any such algebra can be decomposed into subdirectly irreducible algebras Using this general theorem of universal algebra it can be shown that any distributive lattice is isomorphic with a ring of sets

In groups rings and many other algebras all congruence relations are permutable it follows that the congruence relations form a modular lattice Th

f t, comb ed ith the ext nce of e-eleme t hageb a perm t th dev l pm t f an e t tive set e th ory tl t incl des l f t i at orem d ppr priat f t nes co l t n ly l tt ces them l es t fy a que f c zat on theo m but f r tl er re n

It is mportant t te that th latt ce p od t l m l ed in the t t m t f tl pr ced p fet zat n th em one f tl t l e e t ns f ge e l thm t c f pa t ll rd red t h h e t n the us al card n l an l l n l thm t as a pec l ca Tl th m st g n r l t Bool al b a j t wle t th el l mbe t d a fi te l l n imbe

I th ea f gr p st des f th l tt ce f all hero ps ha al bee m de b t l a n t y t led ith d ery of fru tf l l tt ce th eor t e m thod re gr r ll t m h of a pos t tur t y t o n abo t n mod l l tt ces s n if th y ar emimod lar (as the ca e of th latt ce f ll part f set I) A e t res lt D l rth heorem, h h tates th t ry fi t l ttice m rph th a s t l tt ce of fi ite semi mod l ttice m l rly P M Whitman l a h tl t ry latt ce is m rph e th a bl tt f th ttice f all part t f s m (fi t) la

It as m nt ed bo e that th (−1) l m l j ectu eom try P (F) o a l y g F al mpl m ted mod l latt ce Th most nterest g ppl t s f latt c th ry t ge metry m te f th bs rv t F ta e l t P be any bst ct p j ct g m try d f e l by in d ce rel t Th P s l a c mpl me ted mod lar l tt ce Co rs l any fi t -d m n o l mpl m ted mod l r l tt prod t f p jec ti m t es d a Bo l n alg b

Th p d n bst a t e mb t ial appr ch t p ject geom tr es led t th t u t 1936 by J n N m n of h s cont n u -d m n l p ject g m tries (called c nt g me tries) O F k 1946 de l ped par ll l the ry f p ject g m t es f d c tely fi t d me n B analogy affi geom tries a l be rarded as latt es b t th pp h h f led t less mpl and les t k es lts

Relat on to set theory and logic I t the ry n is f eq tly c ned w th s pe al f m l es f sets h as cl ed ets open s ts m bl t d Bo l ts Som f thes f m l f m Bool an al b as B t th cl sed t (d d lly th pe ts) (t p l cal pace X lly f m l t u mpl m ted d t b t e l tt $L(Y)$ l $L(X)$ th mpl m ted l m nts (wh h c rly f rm Bo l n lg b) th e wh h d t X

Both th theo y f fi te t d th th y f fi te d trib t l tt es e f ly t t l Each s h lattice L ha qu r p tat as th card l po L 2 f th t el m t Bo l al b th a g l fi t partially o d d t P as e po t M y fi t -d m al d t b t l ttice fi t

If L fi te d m al l tt d t b t n t, th n d fi l t pol m L

which may mas n t be eq al nt M t f tl es ar ggested l a e n ler t m f tl pe l e tl t I t th rat l n ber st m A l J t m Dedek l e t a f t l wn 193 l y H M M N ll ne can xt n l any l tt (r part lly l ed s t) t c mpl t l tt in wh h any l t f f el m nt x h a l t upper bou l (j n) $\vee x$ l gr test l bo l $\wedge x$ In su l a c n pl t l tt e on ca l f n l m t p j j n l l m inf j j f ns eq ce x_1 x x_n of l m nt One c l fin a e ns g n t pol gy in I l y l tt g $x \to x$ m a tl at l m j {x j = l m inf j j = x Alt ti ly e n l f n n nterv l t p l gy l y tak ng cl ed int r al [b] cl e t t of ll $x \in I$ w tl $a \leq x \leq b$ a l ba f cl ed et

The co c pt of co rg n in latt ces a d tl r p ces ca be t led l y n l ring l r cted set f n l ces a tl cept it lf be ng l ttic theoreti T les r be e n g ce n t pol g cal paces n t sat fy g t t l ty x m s cl l r cted sets es e l l

U g tl e ncepts f l tt mpl t e an l l tt ce t pol gy e a g nte est ng ha a t r zat f ar t s latt es a oc ated th t pol g l spaces Th tl s l ne f tl e l tt f e gular pen t l y S Ulam l C B M ff It was l n f r th (d tr l ut e) lattic f t n fu ct by Irv Kapl ky F ally t a l f r l ed (l pen) t l y J C C. McK nsey and Alfred T rsk ll nc 193

A nt est a l g bet ee t th ry n ll t pr ded l y tl j r l n between th al bra f pe ts n l ll e n l g whi l t nt ly f m a c d at n of f rmal l g c Al t a tly l th d l w th r lat ly pe l c mpl m ted d t t t e l tt ce

A the type f l c d rectly ggested l q a t m th ry was d el ped n 193(l y C B M ff l l Ne m n l tl l m p pe t f rm an th c mpl me ted mod l r l tt ce Th Ar t t l an l c f l l me han s a pe rs tl pec al d st b t n (the Bo l) ca f permutat l b at The f rmal p pe t es of the pr bab l ty $p[x]$ of e t x sh n t be m l r t th e f d me n a p j et n metry

Latt e theo y ls g es pe pe t the kin ls f f rmal log c l d mod l l gic a d t t t mpl cat ll s nce the deepest p blem of f rm l logi c cern th f nd t o f t theory thes ppl t n w ll not be d u ed l

Lattice-ordered groups The first t dy f l t t e-orde ed g o p w made i 189 by Dedek n l n lyz g th p pert es f th r t n l numbe sys t m R Lett $\leq b$ s gn fy th t $m = b$ f r m nt g r m (that th t b t a m lt ple f) the nz r t l umbe f rm latt ce n wh h $n\, b$ d $u\, b\, a_n a$ m th l m and gcd f a d b Al w th pe t t o d ary m lt pl cat n the nze r t ls f m a (mmutat) gr p F lly R

$$a \leq b \quad \text{mpl} \quad \leq bc \tag{4}$$

t ch cal la gu y gr p t sl t n a l tt a tom ph m A y l ttice L wh h i l

group and which shares this property is called a lattice ordered group or l group

Though many noncommutative l groups exist it is a striking fact that every complete l group is necessarily commutative

Lattice ordered groups arise in function theory as well as *in number theory* If $f \leqq g$ means that $f(x) \leqq g(x)$ for all (or almost all) x then most function spaces of real functions form lattices They are also commutative groups under addition Moreover

$$f(x) \leqq g(x) \quad \text{implies} \quad f(x) + c(x) \leqq g(x) + c(x) \tag{4}$$

for any $c(x)$ this is simply (4) in additive notation Hence most (real) function spaces are l groups In addition they are vector spaces in which

$$f \geqq g \quad \text{and} \quad \lambda \geqq 0 \quad \text{imply} \quad \lambda f \geqq \lambda g \tag{4'}$$

The l group with these additional properties are vector lattices Although E H Moore and F Riesz had discussed related ideas earlier the first systematic analysis of vector lattices as such was made in 1937 by L V Kantorovitch

The application of vector lattice concepts to function theory is still not very far advanced Using the intrinsic lattice topologies defined earlier and others related to them one can avoid the necessity of introducing a distance function in many function spaces Thus the notion of metric boundedness is equivalent to order boundedness for functionals on any Banach lattice and metric convergence is equivalent to relative uniform star convergence in a purely lattice theoretic sense

An additive l group which is also a ring and whose multiplication satisfies the partial analog of (4)

$$\text{if} \qquad f \geqq 0 \quad \text{and} \quad g \geqq 0 \quad \text{then} \quad fg \geqq 0 \tag{5}$$

is called a lattice ordered ring or l ring Such l rings have been studied systematically only since 1955 a typical theorem about them is the following An l ring is a product of simply ordered rings if and only if it satisfies

$$a \cap b = 0 \quad \text{and} \quad c \geqq 0 \quad \text{imply} \quad ca \cap b = ac \cap b = 0 \tag{6}$$

Applications Already it is clear that the concepts of vector lattice and of l ring are essential in various physical applications This was first apparent in connection with the ergodic theorem as proved in 1931 by G D Birkhoff and John von Neumann for the deterministic processes of classical mechanics A generalization of this theorem to stochastic processes whose natural formulation is based on the concept of a vector lattice was proved in 1939–1941 by Shizuo Kakutani and Kosaku Yosida

A second application is to the theory of Reynolds operators or averaging operators arising in turbulent fluid motions The essential connection with the order relation is simply the obvious principle that any average of nonnegative quantities is nonnegative Using this principle and the theory of l rings one can decompose (subdirectly) any vector averaging operator into scalar components

A third application is to the concept of criticality in nuclear reactor theory Neutron chain reactions involve the birth (through fission) *migration* and death (through absorption) of neutrons The laws governing the evolution of the statistical distribution of neutrons (as functions of position x velocity v and time t) evidently carry nonnegative distributions into nonnegative distributions To deduce the mathematical principle that the neutron distribution must satisfy the asymptotic relation $N(x, v, t) \sim e^{\lambda t} N_0(x, v)$ λ^{-1} being called the reactor period it is a most convenient to reformulate the problem in lattice theoretic language One can then apply results of Oskar Perron G Frobenius and R Jentzsch on positive linear operators to prove the desired result

See LOGIC RING THEORY [G.BI.]

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Lattice constant

A parameter defining the unit cell of a crystal lattice that is the length of the edges of the cell and the angle between edges If the unit cell is a cube the side of it is the lattice constant and it is usually in this sense that the term is used The lattice constants of simple compounds of the type AX AX$_2$ having the sodium chloride cesium chloride zinc sulfide or calcium fluoride structure have values between 5 and 10 angstroms The lattice constants of the elements and of a variety of compounds are listed in the reference given in the bibliography *See* CRYSTALLOGRAPHY [W.D.]

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Lattice vibrations

The atoms in a crystalline solid do not sit motionless at the lattice sites of the crystal but undergo periodic oscillation about these sites which are positions of equilibrium As the crystal is heated the amplitude of the vibrations increases If the heating is continued the temperature of the crystal eventually reaches a value at which the vibrations are quite violent and the atoms then break away from their lattice sites The solid can no longer retain its crystalline form and melts On the other hand if the crystal is cooled to the absolute zero of temperature the amplitude of the vibration does not subside entirely A residual vibration of the atoms which is quantum mechanical in origin remains It is called the zero point vibration

Lattice vibrations are involved in many of the temperature dependent phenomena of a solid For example the electrical resistance of a metal at room temperature arises primarily from the scattering of the conduction electrons by the vibrating atoms

The h gh r the t mperature a d h nce the more lent the ibratio f th at m the m re the electr s a e c tte ed and the higher the electri c l res tance be me A ferr m g et ld l e- comes p ramagn t at temp r abo e the C ri t mperat r bec u e the lattice vi ratr n r th ffic entl energ t c t m th t atom mag et c f The Bardeen Coop r Schrieff r the ry f percond ct ity p t l t that btle int acti between l tt ce ibrati ns d co d ct electro a e mainly re p ible f th ph n m n n S SUPERCONDUCTIVITY

Latt e l t n ond t h t thro gh a c y t l so a k o ledge f th ibrati mech ni m i e sent l t an nder t d g f the heat co du tivity of cry tall e sol d

The theory f l tt b ati began an eff rt t e pla p ifi heat Theory h w that th f l t tm nt f ib ti n f t m n sol d le d t th D long P tit l w f pec fic he t a law wh h t ot beyed at all t mpera t e (SPECIFIC HEAT OF OLIDS) T ace t f th f l re Albert E te f rm l ted a theory h h umes th t ch t m b tes w th th same f q n d th t the rgy f vil ti q a t zed Th n foll d the mpro eme t n the theory m d by P Debye a d by M B rn d T n Karm n l both f th se theor e th ngl Ein t f qu n y pl ced by n ac u t l pe trum Th th y f B n d n Karm r q r that th pect m b bta ed fr m th t dy f th nb n f s tem f po t p ticles d trol ted m th m m n the t m a y t l tt e Th ri a m del repr sent g a g en l d d ffer l m o a the esse ti lly the a mpt m d ern ng th at f th f es betw e the con t t ent p t l ft u ally the n l th B n Ka man th ry and t te n th t n pe k f l tt b ati n

One-d mensional lattice Som f th m in on ept f the B rn n K m th ry ll s- t ted by th br t f a s mpl one d m n l l tt e F e l sh w uch l tt e m po d of q d t t id nt al p rt l f ma M Th q l b m pa at on f ghb ng pa t les Th y loc t d l x th lo- cat n l th th p rt l be − a A m th t th f es b t n th g ti l e ff t ly betw e t hb d that the e f be Hook law l F l th f c a e rep esent d h m t ll by pri g w th H ke co t t

Let d t th d pl m nt l g the x f th th p rt l f om t l b um p t t na Th f ex t d n th th p t l d pe d p n th d t n wh ch th tw p i g nected to re stret h l The exten on are $(u - u\ )$ f r th left hand pring and $(u\ - u\ )$ f r the r gl t hand pring Th u tl quati n f m ti n f th nll parti l

$$M(d\ u\ /dt\ ) = -\alpha(u - u\ ) - \alpha(u - u\ ) \quad (1)$$

Let the length f the lattice l $l = Na$ tl at there are $(N + 1)$ particles in all The n mber N t taken to be large c mparal l with A eadr n ml er that wheth r tl e d j rti les are fre t m e o e f ed in p ti n s of no practi al importan e he e T l e Eq (1) wr t s ntati ly the eq ati n f a w e of fr q cy and ampl t de A namely

$$u = A\exp[? \ i(\ t - k\ \ )]$$

where $k = 1/\lambda$ the re iproc l of tl e wa l ngth ll we er th lattice di cret and tl was l a n real e i ten e between tl e at m Th lead on t put $x = na$ The tr l s l t n n w

$$u = A\ \ x(\ [2\ i(\ t - kna)] \quad (\ )$$

S b titut n h w that thi pres ati fies Eq (1) pro ded that

$$= \quad n - k \quad (3)$$

wh e $= \sqrt{\alpha/-M}$ It d t tl at t tl highest p rm ll frequ If tl en l pa ti l are med t be imm al l th n tanding wa lt t re ppropriat and ar an l g u t th e f the tt t ing w th f ed end Tl e tri t n n the wa el gth ar $j\lambda/\ = l$ wl re j is an int g ndic ting the number f loop in the part lar ta d g wa e Thu Eq (3) l e- comes

$$= \quad \mathrm{in}\ (-j/2N) \quad (4)$$

the a ge f j being $1 < j < N$ Each kind of l a t is called mod f br t nd tl r i s m d f ibr t f a l j Th th e r N mod s The t t l mbe f modes al qual t the mbe of p rt cl l eca N d N + l e b t eq l

Th ph e l ty U a d th g p locity U an b le lat d f m Eq (2) i ng the d fi i t $U = \ /k$ a d $U = d\ /dk$ Tl lt r

$$U = U_\infty \frac{n\ \pi ak}{\pi k} \quad (5)$$

d $$U = U_\infty \cos \pi ak \quad (6)$$

H e U s th l ty of nd t l ng w e- l gth and h th al e $-a$ o. By l g w le gth is m a t w le gths whi h a e t m dt th eq l br m d in ea

An imp rt t ch a t r t re aled by th tre tm nt the d p d of the loc ty on w el gth S h d p nd n alled d per i le b m gly imp rt t s the wav le gth pp o h th al $2a$ At th cut ff w l gth $\lambda = \ $ th gr p el city zero A t nuum th ory h a D bye s g s s mply

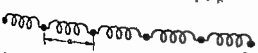

Fig 1 O -d m l l tt f q d t t d t l part l

$U_p = U_g = U - \pi a \nu_0$ = constant and the medium is dispersionless

The number of modes $g(\nu)d$ with frequencies between ν and $\nu + d\nu$ can be calculated from Eq (4) by noticing that this number is also given by dj From this the distribution function $g(\nu)$ is

$$g(\nu) = 2N/(\pi\sqrt{\nu_0 - \nu}) \qquad (7)$$

Figure 2 shows a plot of $g(\nu)$ for the lattice as given by Eq (7) and for the Debye continuum theory The latter is simply $g(\nu) = 2N/\pi\nu_0$ with the range $0 < \nu \leqq \pi\nu_0/2$

The energy E of the lattice is given by

$$E = \int_0^\infty \frac{g(\nu)h\nu\, d\nu}{e^{(h\nu/kT)} - 1} \qquad (8)$$

where h is Planck s con tant k is Boltzmann s constant and T is the ab olute temperature

Three dimensional lattices In three dimensional models some attempt is usually made to approximate the conditions in actual crystals At the same time the considerable mathematical complexity of the problem requires that the model be kept as simple as possil le A decision ha to be made concerning both the number of neighbors to be included in the calculation and the types of forces acting between the particles before the equations of motion can be formulated

The forces are of several kinds A force which arises when the distance between a pair of neighbors changes is called a central or radial force This is the type of force assumed for the one dimensional lattice discus ed earlier If a change in the angle between the pair of lines joining a given particle to two neighbors (bond lines) gives ri e to a force the force is called an angular force A more general force compounded of radial and angular forces is often referred to as a noncentral force The mo t general combination of noncentral forces compatible with symmetry requirements

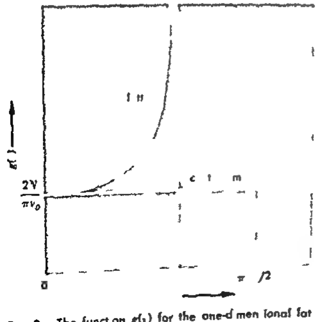

Fig 2 The function $g(\nu)$ for the one-dimensional lattice and the one-dimensional continuum

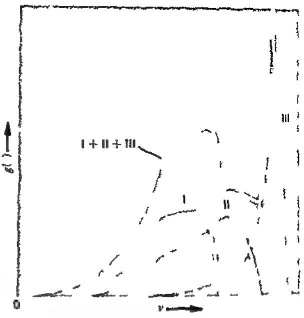

Fig 3 The function $g(\nu)$ obtained by Leighton for a face centered cubic lattice (After R B Leighton Rev Mod Phys 20 165–174 1948)

about the particles is commonly called a tensor force

The types of forces just named are defined for a pair of particles or a pair of bond line The motions of the other particles or bond lines in the vicinity of the pair do not affect the force between the pair In metal however the conduction electrons give rise to a type of force which cannot b defined in this manner To visualize thi imagine that a group of particle (po itive ions) move toward each other thus increa ing the local den ity The corresponding increase in po itive charge density is immediately compensated by a flow of conduction electrons into this region However th compres ibility of thi as eml ly of electron called an electron gas is small and the gas re i ts this increa e in its d n ity The electrons would thus screen the ions le s completely the ion would repel one another more trongly and con equently a stiffening would occur in the elastic constants involved To summarize additional f rce ari e to oppo e any change in particle den ity This i clearly a cooperative or collective effect not covered l y the type of forces ju t li ted The forces produced l y this collecti e effect are sometime called volume for

A common objective of the theory of lattice vibrations is tl e calculati n f the di tril uti n function $g(\nu)$ Analytic method generally cann t l e u ed and the calculati n mu t l e d n numerically R B Leight n (1948) calculated $g(\ )$ for a model f a face centered cul ic lattice with central f rce l etween neare t neighl or and l etween next near t neigl l or Figure 3 sl ows hi re ult obtained after much lal r f r a electi n of force con tant approximating opper The availal ility of high peed digital c mputors ha n w reduced th lal or to th extent that cal ulati n of di tril ti n functions are l e oming increa ingly c mm n

Fgure 3 h w three bran he f the d trl u f t l beled I II a d III In an la u call t-otr p sol d bra ches I and II w t l l o respond t t a wa e and br nch III t l ng t d l w f r λ ≫ a I n l t ally anisot pic cry t l ery few wa es ar pu ely tran er e o l ng t d n l even f r λ ≫ 2 Thi m tual cry t l the wa es co t tuti g branch I d II ar ly p ed mi ntly tra r t hara t r nd th e t bra ch III lv p l m anil l ngit d l Latt es n whi h a l at m bas e ctly th me e tr nm t s any th t m re B a latt a d th e alw ys ha e three bra hes in the d t but n fu t n Th d strb t l nct l n n Br ai lattices h a \ Cl nd d m d ha e add t nal h gh fr q ncy b a h lled pt al bra h The I fequ y br n hes, rr p d g to th three bra ches f th Br s l ttices, are alled u al bran hes.

Experimental studies The e lt f the calc l t l g( ) f r a gt n model e ften tested b e mp t g the pe fi h at and il n mp ring th res lt th the m ed pecifi h at The c mparison h h ha e bee m d le little d ubt th t the B n on Karm theory e n a cou t sat f ct ily f r th d erep nc es betwe n th Deb theory of specifi h at nd th exper m t l m u ment P ec agr ment between th al btai ed fr m th pec l mod ls nd xperim nt h n t t been a h ed h w A part l r d d t f th p f l at app h s the t ty f th pe fi h t t the d tailed h pe of th d trib ti n f t n f r f e q en bey d th fir t p ak

An th p im t l pp h s the t dy f th sc tt ri f r ys by l tt e b at A t t l ttu e h ld p od harp d ff cti pat f s c nf rm ng t th g l rity f th latt If a w p e th gl s h a l tt e a peri d e r t od ced the l tt ce d a p l p ts (gh t) may oc n e th r side f th g n pal d ff t m umum If th mbi ed ffect f ll po ble w t de ed th es lt b o d diff ed p t e te ed t th d ff et m imum Th theory of th eff t w fir t g 1918 by H Fa n d p m t lly b rved 1938 by J La al Th th ry nd p rim t l method a n w dev l ped t the t m th t d per n urves f l tti b at n n b d t m ed f m th ob rvat Th r d t m ed f r pec al d ect th ry tal s g m no- brom t c x r ys. Th d pe n urves bta d a th mpa ed with th n by a mod l P m y d ffi ult e e the c ct f Compt sc tt ri g a d th d t rm t n of th d pers rv a t e d C n all th m thod seem t b poo t wh e the p c fic h t m thod be t th t th t m th ds an b used d t g u l t uppl m t the A th d e p m nt l pp o h th tudy f th l t tt f ld (ery l w) e tr by latt ib at It p bl t u

alm t m n ucl r mati l am of ne tr n with n erg e e il r lly les th n th e aptured by therm l att ring n p a ag th r gh th l tt Th trary t what happen t x ray f r which th ph t n energ s gr at a t l a ely hanged l y thermal sc ttering Th th ry of ne tr n scatteri bec mes s mpl fied if th scatt ring i also t l r t S NEUTRON DIFFRAC TIO [J D I]

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Launching pad complex

The mpo ite f upporti g fa l ties req ed f r th e ti p p r ti n f r l unch and la n h l a g u d l a ed rock t pr p lled h l Th e fa l ties ary fr m a imple tru k m unted ra l g in th ca f a m ll t ti al l l pr pell nt mi le t th pe ma t mpl x f eq pm t d ut l t es req ired f r th pp rt f larg l q il pr pell nt m iles i a es a cl n l level pm t pr gram (Fig 1) Th latt will l d ribed f r t

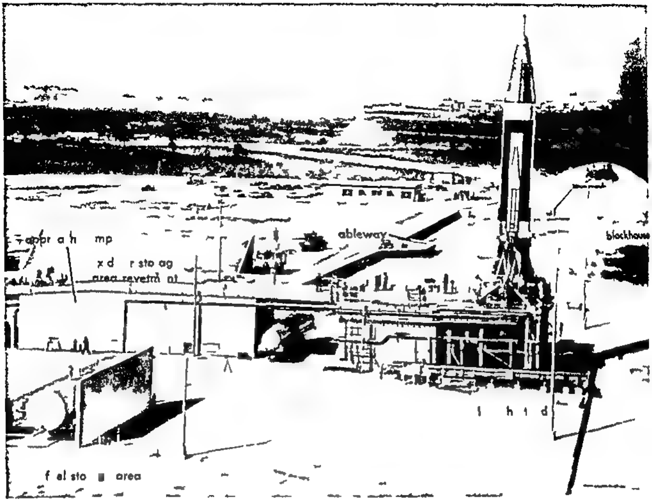
Launch stand The l i ch tand in l des fa il t es fo m ta ni g the m il i th rect po t n wh le fa t perat n a e perf med h a check t of l y t m an l i tr m nt t n ful l ad ng w ghi g and th r la h t d p para tio f r m il flight (F g 2) Spec l f il t re ft p d d f p rform g xtended e g fiti g th lau ch tand either t t t or e t bli h d es f r l n h Thes i l l w t co led flame d fl t r f r d e ti g th en gine hau t d a h l l d wn an l r l a y t m The l tte q i m nt u lly w k ju t n with th weigh ng a d tl t m a g d es

Th w igh y tem a p t l ly important t f t d equ pm nt it m y l u ed fo w gh ng the m il d t m g th am nt f p pell t l ded a g the thru t t t test a d est bl h ng ept ble thru t pe f rm a c pt t l ch ng f m le W ghing m ha m ge rally l ad cell tr g ge

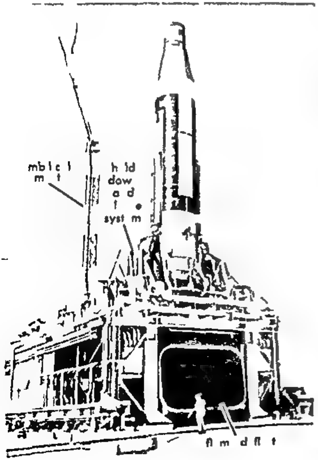
An umb l alt w s ft p ided fo upp rt t g th w ght f th cables g l es d f l ng l e wh h q r n t t th m l ipt th t m of la n h

I dd t t thes fi d t ms a rvc t w r g nt y s p o ded f r p m tt e t th m l wh t d k s n pr g es Th rv e t t d gned t surr d th m l p rt all with r t t bl wo k platf rm t t d t l l wh h r p nd t m l c d (F 3) S h des gn p rm t techn s t rv e d t t t al t m of m l bo q p- me t wh le th m l st nd t The ers t w r lly d gn d t f ld b k r ll w f m th m l t k

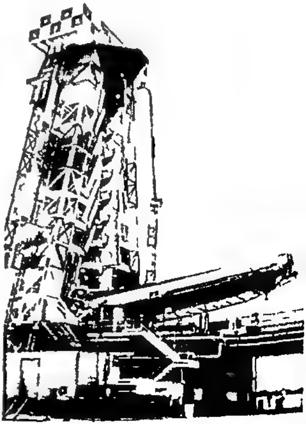
B the t g tu g b l ty f m l d pe d p k l dg f l n h nd t g t



Fg 1 Atlas ICBM fl ght test la nch compl x



Fg 2 Launch stand for l qu d fu led ICBM



Fg 3 Service tow mi le b i g er ct d

Fig 4. Th IRBM blockho se

Fig 5 Rec d' g f typ c l bl kho se

locat o acc rate geodetic rvey f th la h s te is gu ed F rth m re n opt l lignm t stati n u u lly n l ded t the ite f r th p r pose f est bl h g r f n a es f th m le guid and m l y tem

Ber u e afety c n iderat n l n t fr t l nd b ers t n ati t r m t am ra and l ed l oj tel t t n sy tem are generally m l ed in the v c n ty of tl stand f r l rying a l rec rd ng e nt dur ng live pe ati n

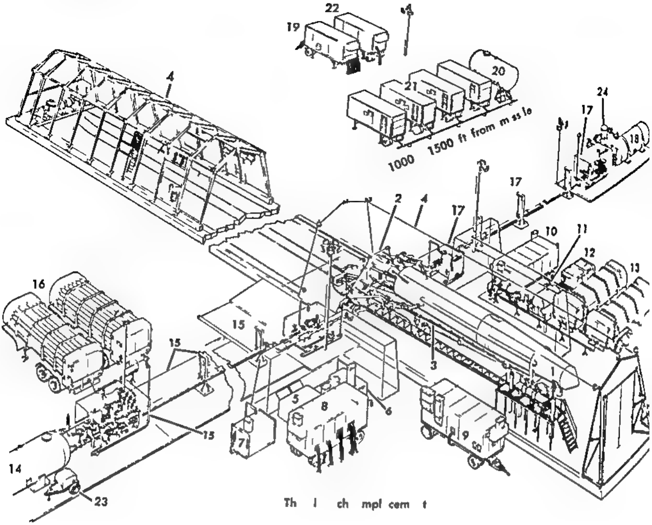
Tl e laun h m d an l ervice t wer may incl ide a c mplete water del g y t m l r ntr lling f res Tl i but n f many mean pr ided t pro tect g r n l a d eq ipm nt

Blockhouse A typical f ed mpl f r l rg el i le m l d a l l kh t designed t pr t t men a d q ipm nt fr m l la t r f l ring a n r mal la n h r f m accid ntal exp l i n f tl e l le during te t (Fig 4) The l lockl i e c n t m te t and tr l n les a d rec rd ng qi p m nt th t the m le may be l ecked an l fi ed r m t ly and d ta f m test rec rded a t mat c lly (Fig 5)

Tl d g f the l lockh i will depend ipon tl l a te ties l tl eh l t be test d In design ng it pr tecti feat res m take t n id rati n th destr ti f r es resulti g f m tl l igl t rder e pl i n tl v h l p pellant m y l pected t p l e t spec fed d tan e f m ll blockl i e W ll thickn es may r ng from a f w fe t er l f et an l v rying tr ti tecl n q es m y be i ed A typ ll rge l lockl u des g ed f r th T tan pr gram i n tru ted l app x mat l 5 ft f rei f rced c n ete c red w th m i f t of l under a t t i g l yer f t l m h nd gun te It will with ta d er p es ponding t n pl i f 50 000 ll f TNT at d ta f 50 ft

Blockh u d or h ld be des g ed t w th t nd th am r p es re a the w ll of th

Fig 6 Blockh f m ll l d p p ll t d dy m typ m f



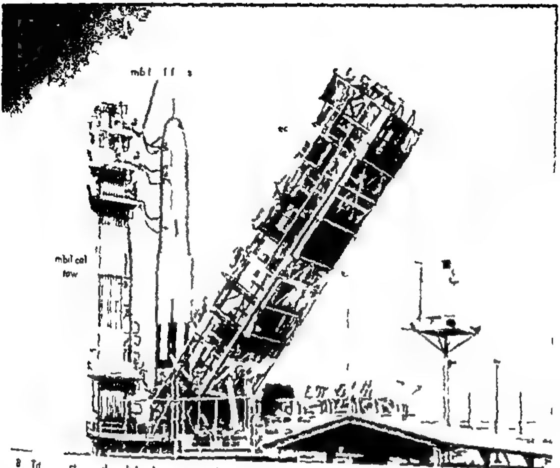
Th l ch mpl cem t

1 Th m l
2 b ll t m ss l e ect g l h g m t
3 b ll t m l m t le
4 p l d p f b t d b ld g
5 hyd l mp g t
6 t l m t d d t
7 k d m t d pow w t hb d
8 t l m t d m l l h g o tdow g p
9 t l m t d b ll t m l y t m h k t t t
10 t l m t d hyd p m t c yst m c t ll
11 h gh p s g t g t k
12 p w d p t g mp
13 mp d g s yl d s m t l (g s t g)
14 l q d yg st ag t k
15 l q d yg p p l tfit
16 mp d g cyl d s m t l (g s s o yg)
17 f l p p l o tft
18 f l t g t k
19 t ll m t d pow swit hbo d
20 d l f l sto g t
21 t l mo t d d l g g at s t
22 t l m t d l h g t l g up
23 t l mo t d m mp
24 t l mo t d f l flt t

F g 7 La ch g s te for Tho m s le T l mou ted eq pm nt erects checks out f el and f es th mis s le

tructure it elf Baffled underground e cape hatches and tunnels are ometimes u ed o that in e ent of a missile crash near the l lockhouse door a safe exit may be made by the per onnel in ide Air intake for the air conditioning sy tem will l e through such remote e cape tunnels if po il le During a launch all fresh air intakes are clo ed and only re circulated air i u ed Blockh u e for smaller mi ile may safely include peri copes for visual b- ervation (Fig 6)

The l lockhouse is connected to the launch stand l y a cal le al e or l low ground wl ich i u u ally prot cted against destruction l y f re or l la t The cal le may contain hundred of wire pair thro igh which monitoring and control signal pa during ground check out and initiati n f th la inch pha e Terminal room are pr ided at tl l lo kh u and la incl stand f r acce t all tl c nd i t r pair The e ro ms may al ntain c n trol an l rec rding e juip m nt a well a e mpon nt



8 Tri ct d mb lc l tow m s'l ct d

the tim ng l nch q e c ground support
l mm nications equ pme t

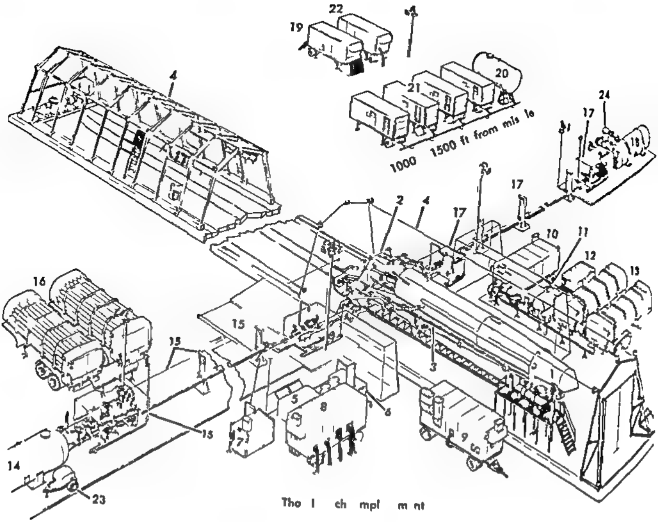
Ground support equipment The m tu e and t of gr d s pp rt equ ,me t (GSE) var es tl f m m l t m ssil B dly GSE all m d eq pme t es ry t t a port erv ce L e nt L a d la n h the m le j o d ng that equipm nt furn l ed s part of th h le tem (F'g 7) I th gr p ng a h ndling pm t tr port t a l r th rv c tow l ect ng m ha m a mbly and l h te t pment a d s les w gh g m ha m bil c l yst m tr l nd n t ume t t n d tl e t l qu pment ta l ed t the le and req ed f r t p epa t on nd p n F ed t m tl f c l t e gr p re llyex l d d f om th GSE ategory

Test nd ont ol f ct n lude mean for re- d ng th rw d play g r ti l mea t ll a mea f r t t g and d t at d w bo d th m l C t al p met s h s p ltages a d l y cl r m t served to p t ev l t n f m f tatu rta f t m y be ut mat c lly eq d np ed d ev luat d nd th m y b e ed ent ly t m l per t n bec f the ty f th e c e f huma jud m t

Fueling facilities F ch launch n mpl x f r l quid fueled m les h fuel and xid zer stor ge a d l ad ng sy t m O di er f the c y g n c (l w t mp rat e) type ntr bute g eatly to th mpl xity of the lau chi g fa il ty St r g m t be pr ided lo e en ugh t th point of u o th t ap r zat f the l q i d d e m t take pl e at too r p d rat in the tr ler l ne Howev th st age p nt m t b f r gh l k f m th launch p int so that the tak -off bl t w ll n t en d g the t ag ta k

E t m cl a l a s e e ty n ha dling liq d o yg n the m t comm n of o id er Ta ks nd l mu t b th ughly clean E au und r p pe o d t n l yd carbon may omb n with an x di t t e fir r pl s n Filt r mployed i th y tem to trap pa t cle wh ch m y ha b e d tally ntroduced L q id y gen ha a no mal tempe atur of −297 F and t m uni l e th cry gen tanks a e d ble j k ted with a u m th nnula p ce The ent e y t m i u u lly mad of tainless te l for e of leanl nd t gth at l w tempe a tu

O d zers such a f m ng n t ic id pre t d d t o al h dl ng p oblem b c e of their t xi a d o natur



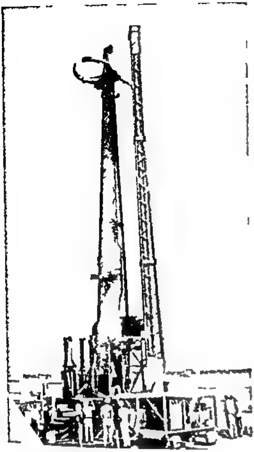
Tho l ch mpl m nt

1 Th m l
2 b ll tc m l t g l h g m t
3 b ll tc m l s m t l
4 pa el d p f b t d b ld g
5 hyd a l c pump g n t
6 t a l m ted o o d t
7 k d mo t d pow w t hboa d
8 t a l m t d m sl l h ng tdow g p
9 t l m t d b ll t m l sy t m h k t t l o
10 t a l m nt d hyd p m t c sy t ms t ll
11 h gh p g ll g t k
12 pow d i c p oc t g mp
13 mp ed g yl d em l l (g o s t ge)
14 l q d yg lo ag t k
15 l q d yg p p l tf t
16 mp s d g cyl d s m t l (g s yg)
17 f l p p l tf t
18 f l t g t k
19 t l m t d pow w t hbo d
20 d l f l to g t k
21 t l m t d d l g g t s t
22 t l m t d l h g t l g o p
23 t l m ted m p mp
24 t l m t d f l f lt t

Fig 7 Lau ch ng s te for Tho miss l Traile mo t d equ pme t erect checks out fuels and f es the missil

structure it elf Baffled underground e cape l atche and tunnels are ometimes u ed so that in event of a mis ile crash near the l lockhou e door a safe exit may l e made l y the personnel in ide Air in take for the air conditioning y tem will l e through such remote e cape tunnels if po il le During a launch all fre h air intakes are cl ed and only recirculated air i u ed Blockh u es for maller mi iles may afely include peri cope for vi ual observation (Fig 6)

The l lockl ou e is connected to th launch stand l y a cal le al ove or l low ground whi h i u u ally prote ted again t de tructi n l y fire or l la t The al le may contain hundr d of wire pair thr ugh whicl m nit ring and c ntrol ignal pa l iring gr und he k cut and initiati n of the la m h pha Terminal room are pr id l at the l lockl u e and l m l tan l f r ac t all th n lu t r pair The room may al o c ntain c m l a l r ord ng equipm nt a w ll a compon nt



Fg 10 Typ l IRBM t p rt e ct mb l l st d l h f p t l

f o ectı f mbl l F mpl f th e h l t t e p mıt c e t m ght be m de ly t th b f th m le, d mbıl al t ld b q ed

Pad for solid propellant rockets I th f ert lly l hed l ge ld p p ll t k t th l h mpl x m l t th t desc b d f the lıq d e pt that th tem q e t the h dling f l qu d m tt d W gh g f the mı le m ght b m p d t ly c mpl h d ın a mbly a, d t t t t w ld n t m lly b m de t l h g te Th h t t d b rn t m f l d es p t l ft ff m k th dry t d tt t e I th s typ f t d th fl m d fl t m y t l m t l with h gh h t p tv p t l m m m y gn th ■ blem lt g th S h m th d l m t th d f gr t q tt f l g t d th l bo t pl mb g y tem q d f w t p d

A sp l p bl m th t w th l d p p l I ts th t f d l w th l g qu t ty f h ghly fl mm bl d lly pl m t l B sol d p p ll t t th m l t th f t ry th t l h t d h k t m t I nd ted w th th m l h za d d F th m ı b y t m ft h k d t p t ly f m th m l p p d

the tıre l ıcle a mbled t the l unch mplex I thı ■ e th mpl x ntaın an ı lated s- embly area w th elaborate af ty and f e-preve t pr ı o

For mall e t ally l unched ■ cket the laun l ıng facılıty ı m h ımpler Tl l l kh m y l e r pla ed l y a c n r t wall a d the laun her and fl m defle t red ed t a te l r ng n crete p d

In the a e of n n rt ally laun hed mı l a ze o-le gth r ra l type launcher ı oft n u ed (F'g 9) The l l ■ c mplex might al c ntaın a comm d tatı n f r pr ıd ng ı tructı n t the eh cle f r l h r rec ery

Operational systems The launch ■ mplex ın the h d f troop d es n t ry ■ fi ntly ı p ın cıple fr m th t r q ed f r test lı t man ch ■ m y l made ın d feren t p ratı nal c ncept The te t f t h nges fr m a p ım ry part f the pr ced e t the m mum required t a h eve h gl p hal l ty of ucce f l la h (Fıg 10)

F mall mı le th l lockh ıı e ı red ed to a mode t tru ture ften a dl ■ revetm nt ff es Wh e m l l tv mp rtant a d po l le e m de f m lt ple p rp l les w th the ab l ty t tran p rt erect a d l u ch ngle mıs- ıle

F l g m ıle requ r ng hea y l gı tı up p rt th e ı n trı ted hard la nch ■ mple Thı ın l ma p te tı gaı t near-direct hıts by e my m ıles In th tvp f peratı n ne may fi d th entır l ı nch c mpl u der g u d w th l y tem w ll d per ed Ma y ı ch m l mple es ca b ntr lled f m a ce tral c mm d p nt [J T]

Lava

M lt rock m t l that che the earth s face thr gh olca e t a d fi res al the gneo r k f rmed by c ol d t f h m l t n m ter l R l t ly rap d ool g at th th f may t f m fl d la ı t d te t ed l nıc rock c mpo ed f tı ery t l gla s b th M lt r k m t rı l b l w th earth f h w ı lly kn wn a m gma d up l ■ gı e t e-gra ed ıgneo r k lı g t gabb

M gm d la ar m tu l l t of l c te m e l w th m les d s l ed g es Whe m gma b ght t th rf c fr m ■ f h gh p e withı th ■ rth th g es e pand d f rm b bbles ın th fl d la If th s l q kly ge l m y f thes b bbles m y b t pped t f m h ghly p k

Th t mp t e f l q d la a ges w dely b t g lly t d n t c ed 1200 C. La poo ın l a (b lt) r th m t fl d d m fl w d wn ry g tl l p f m m l The H waı fl w d mm ly at t f ■ t 2 m l p h S l h l (rhy l t) a e h hly Th y m l wly d f l t l h rt d t A l l t b mes m d th t f fl w d R p d c l

Fixed fuel storage and pumping areas are ordinarily located on the opposite side of the launching stand from the oxidizer area for safety In many systems the more dangerous and corrosive propellants are handled and transferred by means of specially designed trailers Even liquid oxygen may be transported in field trailers with their own pumping and pressurization systems and introduced into the system through a loading manifold Both fuel and oxidizer systems may usually be operated remotely from the blockhouse

A method of dumping propellants is usually provided Liquid oxygen may be dumped into a concrete evaporation pond or a cleared area remote from the launch complex Fuel is rarely dumped on the ground but is either fed back into the storage tank or piped to a fuel holding pond where it can be later dispo ed of by tank truck More elaborate closed systems are required for highly toxic or otherwi e dangerous propellants

General support For static test firings large amounts of water are necessary to cool the flame bucket or flame deflector For the Atlas and Titan missiles as much as 30 000 gallons per minute (gpm) must be provided for a period of 3–5 min It is possible to launch a missile from a dry pad However the dry flame deflector whether it be steel copper or concrete can withstand only a few seconds of flame impingement

Electric power Two independent power supplies are desirable in the launch complex The first sometimes called critical power is accurately regulated with regard to frequency and voltage in addition to being derived from a local independent and highly reliable source Its primary purpose is for instrumentation but it may be used in case of emergency for those operations nece ary f r y tem shut down such as emergency defueling depressurization of tanks and tower erection

The second source of power referred to as utility power usually carries the heavy motor pump air conditioning and ther load required in the complex Becau e of the intermittent operation of s me of these l ads line regulation is not u ually maintained as preci ely as that of critical power

Power requirements ary depending on the mi ile sy tem A typical intercontinental ballistic missile (ICBM) complex may require 500 1000 kilovolt amperes (kva) each of critical and utility power An emergency generator may al o be provided to furni h a few hundred k a f r tandl y

Pressuri ed gas supply High pre ure gas systems (helium nitrogen or b th) are nece ary at the launch complex for li juid propelled mi il Pre ure in the vicinity of 5000 poun l per quare inch (p i) are u ed in t ring th ga e whi h may l e used at omewhat l wer pres ure f 2000 3000 p i There are two method of filling the ga st r age bottle the ga may l e pump ed up t thi pre sure by a multiple tage c mpres or or in the ca e of nitrogen the liquid nitr gen may be pre uri d to 5000 p i and ap rized at that pr ure int th storage tank

These high pressure gas sy tems mu t be kept clean because the gas come in contact with the interior of the mi sile directly or indirectly through the propellants The ga es must also be kept free of moisture because contact with cryogenic fluid would result in ice formation in valves and regulators Also the pre ence of oil in the gas might allow hydrocarbon contamination of the mi ile or the support system Such contamination could result in an explosion when in contact with the oxidizer

Timing and communication Becau e event particularly those telemetered and rec rded mu t be accurately time correlated in a te t ituation the launch complex must either accept externally generated timing signals or generate timing ignal referenced to radio transmi sions from tati n WWV or other standards In the usual ca e where the blockhouse is situated on a te t range the complex will simply provide for connection to an external timing system

Communication is a erious problem during test and preparation An adequate operational interc mmunication system is necessary both within the launch complex and to supporting areas Even with excellent communications equipment the reacti n time of personnel is too long for certain deci i n making requirements Automatic sequencing equipment is widely u ed to provide programmed relay closures measurements and compari on In this way information for many important deci i n may be obtained quickly

Combined erector and tower There are of cour e many variations of the sop histicated y tem descril ed above In ome ca es the erecti n of the vehicle is accomplished by a crane attache l to the ervice tower and a suitable trailer to tran port the missile and offer longitudinal support during the lifting operation In other ca e the ervice tower it elf may serve as a retractable erector whi h re ceive the mi ile while lying in a horiz ntal po i tion and then rai e it to the vertical While in the vertical position the erector function as the service tower (Fig 8) When preparati n are c mplete the w rk platform are opened and the erector is returned to the h riz ntal p ition for firing Variations may exist al o in the meth l an l eight

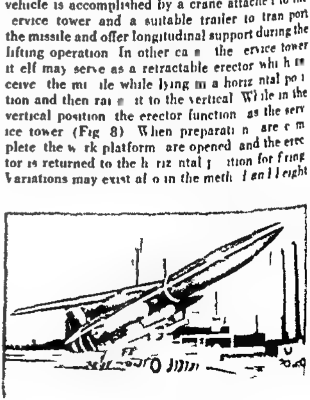
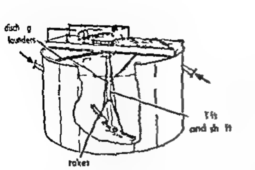


Fig 9 k ze of gth l ch r



Fg 1 Do g t r r (F m W L & dg d J T Ba ch l trod ct to Ch m l E g g M Gra H ll 1955)

l a g en t tal am unt f sol t and al re- lt t nger fi l extr ct

F b th wa h g of pre pitates which ca ot be l ched at facto il in a t nk the Dorr gita t r h wn i Fg 1 i oft u d Th un t i a rti l ta k equ pped ith a lowly tati g rake in th bott m which mo es ettled ol d to th centr f the t k The a ir lift the tt b f huch cts also a the haft for the k l fts lu ry t the l d r wh ch l r tate with the h ft. Th l der d t ib t th s l d er the t p f th l q i d, so the l y ttl s th ugh the l q u d f r dd tio al t b the l e t After d fi t time the e tt e b t h i pumped thr gh filt to p te th sold nd l qu d

Continuous countercurrent leaching Bat h l t nk le h ng ha two d d t ge Fi t the o t f rem g the ol d a d h rg ng th t k m y be h h a d e d e th r th ce t t n f the fi al ext a t low r on de bl n xtra ted solut r ma in the l ached l d The fi t l mitat n i mi m ed by th m f t q pme t in wh h th s l d a d liq d both m d m h ally d th e nd d ffi ulty ed by the u f ere e of le h tank a d the e t rrent fl w f l e t th o gh th t k n er d t the flow of l d In th ay th mo t early xha ted s l d ext t d witl fr h ol ent nd the fre h l id is in cont ct with th mo t c n e trated leach l t n

The c ntu t ou t rcurr nt m tl l i e i cially effecti e in th wa l ing f pr ipitat F r tl a erie f tlick r i u ed (s THICKEN ING) Tl e fl w liagram of an ex mple f th i t m i h w in Fig Tl e purpo e f thi pl nt t make a l ition f u tic oda in water l the a ticizati n of da a b l y the reacti n

$$Ca(OH) + Na\,CO \rightarrow 2N\,OH + CaCO$$

Tl e rea t n it lf i cond i ted in tl three mix i g t nks l own at tl left ha d end of th flow diagr m Tl es ilt f tl e ch mi al act on i tl e f rmati n f a lu lge f CaCO u p n led in a o- luti n of c n ntrat n b it 10% N OH Tl tir rea t n mixt re fl w t the lau der of tl left hand th k ner n wh h it i parated i to a l o e fl w of 10% luti a d a CaCO ludg a rrying a c n id ral l am unt f the soluti n w th it a adheri g l q i d The l dge i e tinu i ly pumped l y d pl r gm pump t tl feed launder f th middl thi kener in which it i mi ed with dil te l t n fr m the r ght l nd thi k n Th fl w l ti fr m tl e m ddl th ken r n w rryi g m f th NaOH l o gl t in with tl l dg f m th left ha d u t r t d re tly t th a t git t r t f rmi l w t r f r th r a t n and f th fi al 10% luti fl ng f om the l ft l d th ke l th right l n l thi k ner th l lge fr m the middle tl i k n r i gi a final wa h w th f esh w ter nt ing fr m i t d Th l dg d harg d fr m tl i thi ken arly fr f ca tic od Add t n l th k n ma be added t the y tem if t ll m re th gl wa l i g f th lid i d ired

Wh n the l d in larg l mp r when th t of l t i l w it t pr t ll t m the l d f m t nk t t k Then a modified c t r r nt meth l lled a Shank y tem a dif f n batte y i u ed Thi m thod g es th eff u f l nt and th w ll-e tracted s lid of the nter ur nt m th d The p i cipl f th

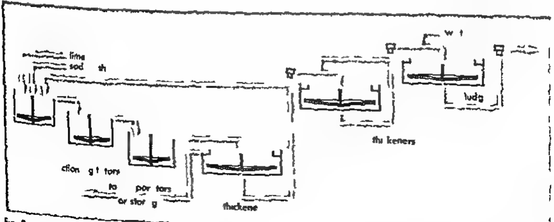


Fig 2 (b) C r t t m sy t m (F m W L & dg d J T B h l t d t t Ch m ical E g ne g M G w H ll 1955)

*ing as at the surface of a flow promotes the forma*tion of glass Slower cooling as near the center of a flow favors the growth of crystal

During many volcanic eruptions the lava is so rapidly ejected that it is blown to bits by the explosive force of expanding gases The mall ma es rapidly congeal and settle to the earth to form thick blankets of volcanic tuff and related pyroclastic rock Lava flows and volcanic tuffs cover large areas of the earth s surface and may form more or less alternating layers totaling many thousands of feet in thickness *See* IGNEOUS ROCKS MAGMA PYROCLASTIC ROCKS TUFF VOLCANIC GLASS VOLCANO [C A CA]

Layout drawing

A design drawing or graphical statement of the over all form of a component or device which is u ually prepared during the innovative stages of a de ign The detail and completeness of a layout drawing are not adequate to ensure a faithful explanation of the device and its construction to any but such individuals as designer and draftsmen who have been intimately involved in the conceptual stage In a sense the layout drawing is a running record of ideas and problems po ed as the design takes form and evolves In the layout drawing for instance considerations of kinematic design of a mechanical component are explored graphically in incomplete detail with only those aspects being stres ed for which graphic portrayal of the elements and their interrelation hips would contribute to the evolving design

In mo t ca es the layout drawing ultimately becomes the primary source of information from which detail drawings and as embly drawings are prepared by other draft men under the guidance of the designer *See* ENGINEERING DRAWING

[R W M]

Lazurite

The chief mineral con tituent in the ornamental tone lapi lazuli It cry tallize in the i ometric sy tem but well formed cry tal u ually dodecahedral are rare Mo t commonly it is granular or in compact mas es There is imperfect d dec ahedral cleavage The hardne is 5–5 5 on M hs cale and the pecific gravity is 2 4–2 5 There is vitreou lu ter and the color i a deep azure more rarely a greeni h blue Lazurite is a tecto ilicate the compo ition of which is expre ed by the f r mula $Na_4Al_3Si_3O_{12}S$ but ome S may be replaced by SO_4 or Cl Lazurite is soluble in hydr chl ric acid with the evolution of hydrogen sulfide *See* SILICATE MINERALS

Lazurite is a feld path id but unlike the other member of that group i not found in igneo i rock It occurs exclu ively in cry talline lime tones as a contact metamorphic mineral Lapi lazuli i a mixture of lazurite with other ilicates and cal ite and u ually contain di eminated pyrite It ha l ng been valued a an ornamental material Lazurite wa formerly u ed a the blue pigment *ultramarine in oil painting* Localities of occurrence are in Afghani tan Lake Bikal Siberia Chile and San Bernardino County California *See* FELD SPATHOID [C S HU

Leaching

The dis olving by a liquid olvent of oluble ma terial from its mixture with an in oluble soli Leaching is an industrial eparati n operati based on mass transfer Example are the wa hin of a oluble alt from the urface of an in lubl precipitate the extraction of sugar from ugs beets of oil from oil bearing seed of metal an their compounds from crude ore and of tanni from tanbark The olvent may be cold or hot wa ter as in the wa hing of a precipitate or the leach ing of sugar beets it may be a pecial organi solvent as in the extraction of oil from eed it may be a chemical olution as in the extracti of copper compounds by aqueous amm nia

Leaching is closely related to olvent extracti in which a soluble substance is di olved from on liquid by a econd liquid immi cible with the fir Both leaching and olvent extraction are ofte called extraction

The rate and mechani m of leaching depen upon the structure of the olid and the di tribu tion of the solute in or on the solid One extrem is in the wa hing of a precipitate where all the lute is on the surface of the olid and i alread di olved in the solvent adhering to the particle In this a e olution is rapid and i complete a oon as the olid and olvent are well mixed as slurry Another extreme i found in the leachin of egetable matter uch as eed or beet wher the olute i behind cell walls or therwi e int mately di per ed throughout the lid truct ire Then becau e the ma tran fer i by the slo proce e of lid diffu ion and o m i c n ider able time mu t be allowed for the extraction A other ituation is found in metallurgical leachin where the metal i finely di per ed in the ore Th ore i then u ually cru hed before leaching to fre the metal fraction for interaction with the l en

Batch leaching The kind f equipment u e f leaching al o depends on the tructure and parti l size of the oli l Relatively large lump of s li are treated in imple ertical tank equipped wit perforated fal e bottom The fre h s li i place in the tank and solvent p ured over it The extrac drains through the fal e b ott m to the b tt m the tank An xternal pump may al be u ed t circulate olvent fr m th b tt m f the tank b to the t p f r additi nal pa thr ugh the l ed olid Wh n the l ent and s li are in eq ili rium the liquid called the extract i drained th extracted li d carded and an ther bat charged t the tank

A more eff ti e u e f ol ent i obtain b dividing the t tal l ent into eral e ual frac ti n and u ing each fra ti n parately with a drain t th end of each treatm nt All xtra t ar th n combin d Thi give a m th rough l ach

Germ , French Morocco S uth We t Africa and Spa n M t of th l d p d ed ≡ the United States is mi ed in M uri with additional l ad com g fr n the estern tat Id l Utah Ari m a Col rado d Mo tan

Lead r ly occurs in it el mental tate Th m t comm o e is th ulfide gal na Th ther ner l f omm ial imp t c are the bo t eru te a d the lf te angl te which emu h m rer re

L d res g nerally occ n nat re ciate l th l er d zi Beca e of it rrence w th l er lead hs th pa t b n con dered a b prod t f l e min g Oth metal m monl occu ing ith lead e ar pper nic tim y d b muth M t of the w rld p d t n of r ic a t m y a d bi m th art es from th sep r t fr m le d or

Comme l l d ≡ may co tain a l ttle 3% l d, but a l ad c nt t f b t 10% i m t c m ≡ Th ≡ ≡ c t ated to 40% or greater le d c t t b f e melt g A var ty f m l m l sep r t n p oce es m y b empl yed f the ce t at f l ad res ▮ t the ulfide r generally c t ated by flotatio proc s e f r h h the r part cul ly table S e LEAD METALLURGY

M e th th d of th l d p d ed n th U ted St t s i der ed f m recl imed l ad l d lly The h f ours e f th s nd ry l d is sc pped t m b le t g l tter The dary l ed bta ed by m lti g of rap a d is ge lly t p fied b t the e r ed l d lloy Sec dary le d i m t ag b tte s n l m nt m nd i r u ed i b tte y m u f ct r Th le d c p h h c ta t re- sed i them n f ct e f ld

Uses A mpled i th d cu n of er p l d bo e th l gest le u e f lead is fo th ma u f ct r of to ge batte es Oth imp rtant p- pl c n e f the m nuf ture of tet aethyl l d, c ble ov g tru t n p gm nts s ld r d mmu tio

Th l d t ge batt ry n t f g t plat f p l ad a p t pl te f l d p r x d d n l ct lyt of ulf d lut Th plat a e mad by c t g pe f t d grd f m an ll y f le d c tai g 7 12% ant m ny d small m t f ts The a t m y s dd d t ≡ the gr d bett h dn s d c osi re t c h th t add d t giv bett t g p perti e The ≡ t g d i ted with p t f l tha g (PbO) m tu f l th ge nd fi el d ded m t ll c l d The p t e grd i ted w th a m xt of l tha ge nd fi ly d ded l ad d m som e ed l ad (Pb O) Af th b tt ≡ e a mbl d and cha g d w th s lf r d the pl te ar f m d by p i g lect r m th gh th m t t th l d d at th gar pl t t fi ly d d d l d po ge d c n ert th lead d at th p t e pl t t l ad p d Th ch m al r ct wh h t k p l ≡ b rging r d h rg ng a

battery are ery mple l t may l e indicated i mple f rm l y the f llowi g q ati n

$$PbO_2 + H_2SO_4 + Pb \underset{\text{Ch rge}}{\overset{\text{D schar}}{\rightleftharpoons}} PbSO_4 + H_2O$$

Be i e ulfur c a d i c n umed li harg of the l att ry the sulf i ic d c ncent at n i used a mea re f t e tate f l a ge f l a l l tt ries

In 1957 an import ≡ add t o t th fam l f l ad l atter was tl t tr l ucti n f a l arg al le dry c ll The l tt ry i c mpo ed f an alkali l ad de-x l r s tem and i apal l of repeated d h ≡ and re l arge witl t aff t g it capac ty Also n tew rthy ar t op r l ility i both l w and high temperature and its l ng term h lf life S STORAGE BATTERY

The ma ufactur of t t ethylle d i the ec nd larg t ≡ f l ad Wl n ? 3 ml f thi antiknock age t are dded t l gal l gs li ≡ the oct ne r t ng of the fuel i ra ed al t 10 tane n mber Thi increa e n o t e n mb permit the i ≡ f high r c mpre i n rat o ≡ aut m l ile eng ne the eby mpro ing gin eff i ncy F r e mple t ha b en h wn that n a age dec ea e i g l c n mpt n f l t 45% can l e ol ta ed i g r g fr m 5 25 l t 10 l mpres i n ratio der nditi n f n t nt perf rmance S ANTIKNOCK AGE TS INTERNAL COMBUSTION EN GI E

T t a thylle d ma ufa tured by the r t on f thyl hl de with n all y f odi m and lead Th h mi l r a ti n s

$$4PbNa + 4C_2H_5Cl \rightarrow (C_2H_5)_4Pb + 4NaCl + 3Pb$$

Lead is melted and mix d with od m t f rm n all y nta ng abo it 10% sod m The l d ll y tre ted with ethyl hl ide n ut cla at m le at t mp rat re nd pres re i the h ence f l e t The crude p od ct i p r t d by team d t ll ti nd i pu f ed by a bl wi g to remo e g c b m th mpound a i g f m bi muth imp t e the o ig al lead met l The t traeth yll d i th n blended w th thyl d hl ide d ethyle d b om d whi h erve a a e ge s t d the r m al of le d d p it f m eng es li ld n thi f rm t p t l um efi r a ti k ck fl d f r dd ti n t th ir a t mot g v l ne t ks In a t ng l ethylen dib om de al n ed s thes ven er

Be u f it e c lle t s ta e to c r s on le d find xt ns e i e i c n tu t parti l ly i th chem al i du try It is e i tant t tt ck by many a d be au it f rm it wn pr t t e xide c at g Bec u e of th ad nt g u char a ter t l d i u ed w dely ≡ th manufacture d ha dl g of ulfu i c d Th ≡ r son re s t e f le d l ut l zed in th c th d c p o- tect of metal t tu e Thi s ompl hed by mp ng lectr h ge n the t uct re t b pr t ct d the tru tu re as the th d lead the a d S h pr tecti u eful f la g t ct e s h s hips p p l s and b dge S e CORROSION

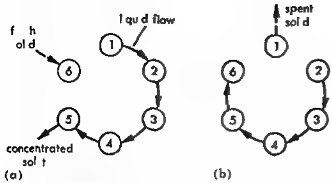


Fig. 3. Countercurrent leaching by Shanks system. (a) Beginning of cycle. (b) First step in 6-step cycle. (From R. E. Treybal, Mass-transfer Operations, McGraw-Hill, 1955)

Shanks technique is to retain each batch of solid in the same cell or extractor during its entire leach, but by appropriate piping to change the flow of solvent periodically in such a way that the charge in any one cell is treated with successively weaker solution until fresh solvent is used, and then dumping the exhausted solids and charging the cell with fresh solid. *The process is shown in* the diagrammatic flow sheet of Fig. 3 which shows a 6-cell Shanks system. In Fig. 3a cell 6 is empty, ready for a fresh charge of solid. The oldest charge is in cell 1, and those in cells 2, 3, and 4 are successively younger, with the freshest charge in cell 5. The solvent flow is in the order 1-2-3-4-5. This flow pattern is maintained for a definitely scheduled time until the solid in cell 5 has been leached to the desired thoroughness, and in the meantime cell 6 is charged with fresh solid. Then *the flow is changed to that shown in Fig. 3b* and cell 1 is cut out and dumped. This cyclic process continues indefinitely.

In practice the cells are usually arranged in a straight line instead of the circle shown in Fig. 3. The piping is arranged to give the same sequence of operation as in the circular arrangement. This reduces the floor area required for the battery and facilitates the use of a belt conveyor for charging the cells from the top. The exhausted solids are dumped from the bottom of the cell onto a second belt conveyor *which removes them from the* system. Heaters may be installed in the liquid flow system between each pair of cells to keep the solvent hot. If the temperature is above the boiling temperature of the solvent at atmospheric pressure, the system is operated under pressure except when the cells are being charged or discharged.

For more difficult leaching operations, especially of oil-bearing seeds, elaborate systems highly specialized for the specific individual application have been developed. *See* MASS-TRANSFER OPERATIONS; SEPARATION (MECHANICAL). [W.L.M.]

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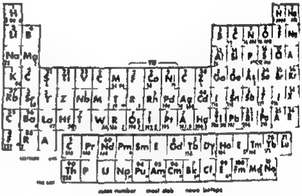
Lead

Chemical element number 82, lead, Pb, is a heavy metal (sp gr 11.34) with atomic weight 207.21. Lead has a bright bluish color which tarnishes to a dull gray. It is pliable, inelastic, and easily fusible; melts at 327.4°C and boils at 1740°C. The normal chemical valences of lead are two and four. It is relatively resistant to attack by sulfuric and hydrochloric acids but dissolves slowly in nitric acid. Lead is amphoteric, forming lead salts of acids as well as metal salts of plumbic acid. Lead forms many salts, oxides, and organometallic compounds.



Industrially, the most important lead compounds are the lead oxides and tetraethyllead. Lead forms alloys with many metals and is generally employed in the form of alloys in most applications. Alloys formed with tin, copper, arsenic, antimony, bismuth, cadmium, and sodium are all of industrial importance. *See* LEAD ALLOYS; TETRAETHYLLEAD.

Lead compounds are highly toxic, and lead poisoning was at one time a common occupational disease. The greatest industrial hazard arises from the inhalation of vapors or dusts of inorganic lead compounds. In the case of organic lead compounds, absorption through the skin may become significant. Some of the symptoms of lead poisoning are headache, dizziness, and insomnia. In acute cases there is usually stupor, progressing to coma and terminating in death. With proper precautions, however, industrial lead poisoning can be entirely prevented. *See* TOXICOLOGY.

Lead is one of the oldest known metals, and the earliest archeological specimens date from about 3000 B.C. It is mentioned several times in the Old Testament, and in ancient Egypt it was used to glaze pottery and make ornamental objects. Lead was used extensively by the Romans for water pipes, even to the extent of being standardized by size and length.

Natural occurrence. Yearly world production of lead is about 2,000,000 tons. The leading countries in lead mining and production are Australia, the United States, and the Soviet Union. However, the United States is unique in that it consumes more lead than it produces (about 50% of the world's consumption). Other important sources of lead are Mexico, Canada, Peru, Yugoslavia,

Type metals Type metals contai 9¼–1 ᶜᵗ ti ad 2½–25ᶜᵗ antimony Antimony incr a e hard ess a d red sh hri kage d ri g ol dificati n mp o es fl dity and reprodu ti n of d t il oth el m t lower the melt ng tempe at ire f i ll y C mmo ly u ed type metal melt at 460–75 F

Bearing metals Lead bearing metal (Babbitt metal) co ta n 10-15ᶜᵗ ntim ny 5–10ᶜᵗ tin nd for some appl c t m ll am unt of ar en r c pper T d ant mony c mbi to form o po d wh h p o ides we r res ta c These ll fi d f eq e t applicat on in ca t leeve bear ngs a d eu ed t n lv fr ght ca j urnal bearing In m a t bea i g b on es th lead o t ima e eed 25ᶜᵗ

Solders A la ge n mb of lead ba lde t p n s ha e been de loped M t ntain l g amo nt of t n w th elected mi or additi n t p vide pec fic be fit su h s impro ed wetting har cter st c

Free-machining brasses bronzes and steels Le d s dded in m nts fr m l t 25ᶜᵗ t bra es a d b zes to impro e m ch ning ch acteri t s Le d eman d c ete p rt cle i the e alloys It is also added t some co t u tion l steel prod ct t in rease ma h ab l ty Only bo t 0 1ᶜᵗ i needed but th to g m l ed i la ge that thi f rms an impo t t e f r l ad S e ALLOY LEAD LEAD METALLURGY SOLDERING T ALLOY [D N W]

Lead isotopes geochemistry of

Th study of the i t p c mpo t n of l ad i mineral and rocks n ord r t el te it to p st as oc t s of th le d w th u i m and th rium Lead h f u i topes f rel tive ma 204 206 ²⁰⁷ d 208 Pb Pb a d Pb a e prod c d b th d o ti d ay f u an m nd thor um Th dec y relat are

U^{238} (half l f 4 5 × 10 y ars) → Pb^{206} + 8α + 6β
U^{235} (half l fe 0 71 × 10 y ars) → Pb^{207} + 7α + 4β
Th^{232} (half l f 13 9 × 10 y rs) → Pb^{208} + 6α + 4β

h e d te lph part l (doubly cha ged h l m l) a d β den tes beta p rt cl (lect o) F m y t m h m ne l o ock prim ry l d i defined s th l d p es ent n the t m t the t m it wa formed d g J d i l ad p duc d in th tem h the d f um d th r m t w formed e Pb t p d ed b the d cay f ny nat lly oc r i g r d ct pe t c n be used d t d t rm the m t l pri m ry le d a y t m P m l ad w ll l de ll l th Pb nd bl mo nts f Pb Pb a d Pb d p d g th rigi f the l d

Fort n t ly omm k h a gr nit s a d b lt y t m l k th ru t f the rth h e fficientl high r t f th m d a um to le d t e m bl ch g th ot p r mpo t f the l d t m nt rval s h rt a ome ten of mill n of year S me m n erals ha e practically all rad genic lead wh le th ers ha e u f l w rati s f ura ium and th ri m t lead tl at the i ot pic c mp it n of th ir lead will n t h e hanged appr ciabl y er th u ands of milli n f y a S n e the i otop c c mpo iti n of l d ob rved in ro k and min al i r lated directly to the am unts of urani m and th ium th l d w a oc ted with in the p t and the length of t me of the a sat n ii i g ll le t gai in format on f om coo dinated st idi of the geochem i try f urani m thor um d lead wh h c uld n t be obta ned f m elem nt wh l are n t in l ed m r dioa ti e d av h in Some example will be gi en t illu trate the uniq e al e of thi type of n est gat n

Variation with time If the uran im th rium and l d ntent a d lead i t pic c mp tion re known f a p rti ular min ral it i po ble to lculate the i topic c mpo ition of the le d at ny t me in th p t if th min ral i pre ent a l ed sy tem A cl ed sy tem i one in whi h the ur nium lead and th ium lead rati ha e n t been ch nged in th pa t l y proces s ther than radio a ti e decay th t i the r tios we e ne r ha ged by h m cal pr ce es It i p l le in prin ipl to treat th o t r porti of the arth a a geol c ay tem a d t t dy the isot pic compo sit n of it lead a a f cti n f t me Meani gful esult an be bta ned p vid g the u an um lead a d th r um lead r tio a e rea ably u if rm th ough ut the y t m r if ampl ng i ten i n gh to a ee g t the local a iations which m y e i t I e ther c s it p sibl then t de term ne the ura i m l d and th r um lead ratios of the y tem prod cing the lead

Th t me var t n has be n tud ed in tw dif fe nt urces pota um feld p r a d gal na Po m feld par (KAlSi O + NaAlSi O) is omm n m n r l i ig e u rock s ch s gra te nd p gm tites Galena PbS mm l c u s i e n f hydr thermal u igin Both mine als ha e h l w uran m le d a d th rium le d r tio that th top mp iti n f the r l ad will not have hang d app e bly s n e th time f cry talliza ti n p o ding th re h bee no n t mi ation f m e t rnal r es Alth ugh pota si m feld par nt i rel t ely mall mo nt of lead (5–100 ppm) t h the gr at d ant ge th t the t m f f rm t f the m e l an b a c r tely d ter m ed by m n the ge of cogen t m e als h a m a ran nite zi n Se ROCK (AGE DETE M I ATION) On th th hand, th e ns f om wl ch g le a i bta n d do n t rule nta mi al wh h are s tabl fo ag det rm nat on th t the t me of f rm t on f a gal na mu t be nf rred fr m ge r l ge logical el t ns S nc l ad a ly bt ned from g le a much m re d t x t f r t th fo igneo m neral although th d t gi n by the latt r b t rp ted w th gr te cert nty

Th t p c e mp ti n f lead h been de term ed f r en pot s m f ld par of k n

Because of the poor structural strength of lead it is generally used in the form of its alloys particularly in combination with antimony or is used as coatings or plates on stronger structural metals Tin alloys are frequently used in protective plates to impart mechanical strength and better corrosion resistance To some extent the lead that has gone into the usual architectural and plumbing applications in the past such as roofing and flashings for example is now being displaced by other material However this decrease in basic architectural uses is being offset increasingly by growth in specialized uses

For example lead has long been used as protective shielding for x ray machines Because of the expanded applications of atomic energy radiation shielding applications of lead have become increasingly important Basically shielding effectiveness against radiation depends on density and lead has the highest density of the commonly available materials Wherever glass windows are required in radiation equipment a type of glass containing large amounts of lead is used *See* RADIATION SHIELDING

Lead has long been used in construction because of its vibration damping properties Heavy machinery and even large buildings are isolated from vibration by placing them on pads of lead In inertial guidance research the experimental chambers are isolated from adjacent ground and structures by the use of massive lead pad

Lead sheathing for telephone and television cables continues to be a sizable outlet for lead The unique ductility of lead makes it particularly suitable for this application because it can be extruded in a continuous sheath around the internal conductors The lead used in this application is generally alloyed with small amounts of arsenic and bismuth

The use of lead in pigments has been a major outlet for lead but is decreasing in volume White lead $2PbCO_3 \cdot Pb(OH)_2$ is the most extensively used lead pigment It is prepared from metallic lead by treatment with acetic acid air and carbon dioxide It is an excellent pigment because of its outstanding chemical affinity for paint vehicles and its great hiding power Pigments such as red lead (Pb_3O_4) and blue lead (a combination of basic lead sulfate $PbSO_4 \cdot PbO$ zinc oxide and carbon) are used as metal protective pigments in paints Other lead pigments of importance are basic lead sulfate and lead chromates The lead chromates are frequently used as dyes in formulating yellow orange red and green paints *See* PIGMENT

The high density of lead which permits a maximum of striking power with a minimum of air resistance has made lead the ideal metal for bullets and shot Lead shot is manufactured by a unique process which involves dropping molten lead into water from height up to 125 ft thus freezing lead in the spherical form assumed by its droplet

Principal compounds A considerable variety of lead compounds such as silicate carbonate and salts of organic acids are used as heat and light stabilizers for polyvinyl chloride plastics These compounds are both inexpensive and effective They function as hydrogen chloride acid acceptors thereby preventing the autocatalytic breakdown of the plastic by the acid

Certain inorganic lead compounds find specialized use Lead silicates are used for the manufacture of glass and ceramic frits which are useful in introducing lead into glass and ceramic finishes Lead azide $Pb(N_3)_2$ is the standard detonator for explosives Lead arsenates are used in large quantities as insecticides for crop protection Organic insecticides have displaced lead arsenate to some extent but not completely because they have not been found as effective in certain applications

[H.SH J.D.JO]

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Lead alloys

Substances formed by the addition of one or more elements usually metals to lead Lead alloys may exhibit greatly improved mechanical or chemical properties as compared to pure lead The major alloying additions to lead are antimony and tin The solubilities of most other elements in lead are small but even fractional weight per cent additions of some of these elements notably copper and arsenic can alter properties appreciably

Cable sheathing alloys Lead is used as a sheath over the electrical components to protect power and telephone cable from moisture Alloys containing 1% antimony are used for telephone cable and lead arsenical alloys containing 0 15% arsenic 0 1% tin and 0 1% bismuth for example are used for power cable Aluminum and plastic cable sheathing are replacing lead alloy sheathing in many applications but improvements in methods of applying a lead sheathing (continuous extrusion) may offset this trend somewhat

Battery grid alloys Lead alloy grids are used in the lead acid storage battery (the type used in automobiles) to support the active material composing the plate Lead grid alloys contain (1 % antimony for strength small amounts of tin to improve castability and one or more other minor additions to retard dimensional change in service No lead alloy capable of replacing the lead antimony alloys in automobile batteries have been developed although research in this area has been extensive An alloy containing 0 03% calcium for use in large stationary batteries has met with some success

Chemical resistant alloys Lead alloys are used extensively in many applications requiring resistance to water atmospheres or chemical corrosion Lead alloys are noted for their resistance to attack by sulfuric acid Alloys most commonly used contain 0 06% copper or 1 12% antimony where greater strength is needed The pr n f a tt m ny l were corr s n re i tan m l gree

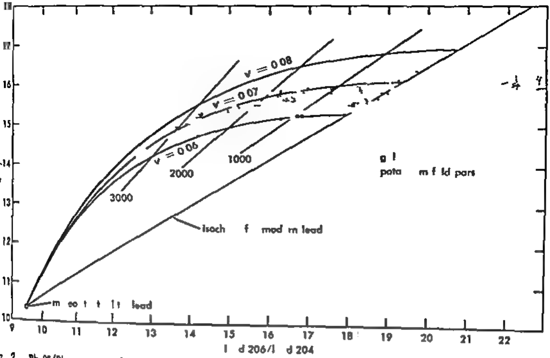


Fig 2 Pb 06/Pb f ct f Pb /Pb 04 t m hyp th t c l f o m ts. Th fo lead fr m g l d f ld p rs Th g f th g wth rv l l t d f u U /Pb earth tak 4.55 × 10 y o ll g l l t m g cl d yst m p t th t m f soch = U /Pb (t m t) at th p se t lead pa t

a d Pb 06/Pb ti f y l d w ll determ ts mod l g

The mod l ge bas d a mb of s mp- t s, th m t t ingent b g th qui m t f a losed syst m the c i m l pt the tim f p t n f th l d d b ce of tami ti f th l d with l d f d ff ent g aft par ti n It n t s p g th t these c diti n t alw y m i (ee f ll w g ct in this arti l n a mal u l d) I f v bl eases, m d l [redacted] agr e w th th g s of s p posedly co t mpo eo oneo ock w th ±100 × 10 y bout th l m t f ccu y f th m thod Th method b tt s t d f d t ngu h ing b t en tw le d f gr tly d ffering g th than f d t rm g p c g F ample, i th App l h an M t g l n f m P ecambrian ock t F klin N.J [redacted] a m del g f abo t 900 × 10 y ars wh l g l a o- ted with P leo k e l l l tes g mod l ges f 100 t 300 × 10 y a Th l tt gal w p b bly empl c d d ri g m ph e f th f rm ti n f th App l hi M ta b lt, hil th P amb n gal nas w e f rmed [redacted] t th App l h s.

F gu e 2 ggest th t l d n g l de ed f m sour n ir nm t wh h h m l d rat s t d ff ri g g tly f m th wh h p o d th l d f d i gneo k The l d gneo ks f ll y t m t lly h l w th ge sot p gr wth c rv f r th gal p h p ting a l ghtly high u m l d ti n

th e fo th g l n lead An ther po ble a f this d ff ce i g en b l w i th sec t n omal [redacted] lena Also m [redacted] analy es f f ld p lead m st be mpl ted t cert i whethe th p esent d ta prope ly hara ter ze ig ne us r k The feld pa dat are ll f m N rth Am i a wh l the gal na dat ar fr m all c nti ne ts e pt g Ant t ca H wever th e s e de ce f t f om c t t to th the g l na d t It str ki g th t th ga l a l ds f m h a cl s ly d fined c rv s c th y [redacted] t mples t k m tly at random o wo ld w de cal

Anomalous leads Th e l d gi e mod l g wh h re l ly rrect. For i ta ce if the mod l ed t d t rm [redacted] s or e t, l ad h uld b f nd t th right of th mod n l ad och n F g 2 (n gati mod l age) F gur 2 d e n t co th f ll r ng of an m l u l ad Pb /Pb t s high 93 d Pb /Pb 04 ti h gh 24 h bee b rv d Th s trem h wev A m l le d ar ge lly h i d by h gh Pb 08/Pb and m t mes by h gh Pb /Pb t o w ll Pb /Pb m y n t b h gh n the ab n dan f U so l w th t ly gl g bl m unt of Pb h be n m d w th espect t Pb r th [redacted] t 2 × 10 y N te that th Pb /Pb rve F g l ne ly fl t th t tum t rv l

A gn fica t f tu f al l d th t th sot p mp t n s n d bly f m

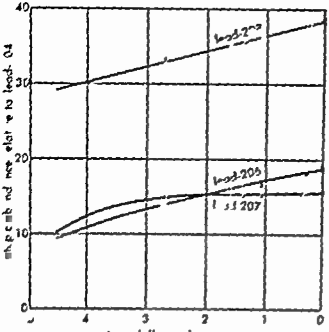


Fig. 1. Isotopic composition of lead in igneous rocks as a function of age.

age covering a time span of from ... to 2.7 × 10 years. The ratios of ... and ... to ... are plotted as a function of age in Fig. 1. The experimental uncertainties in the ratios are ±½ to 1 ... of the ratio; thus the variations are many times the errors. It is seen that the more recently a feldspar was formed the more ... and ... it contains with respect to ..., indicating an accumulation of radiogenic lead in the source environment. All points in Fig. 1 represent feldspars except the ... at 0 and 4 ... × 10 years. The points at the present (modern primary lead) represent the range in isotopic composition of lead from three basalts, a gabbro, red clay from the Pacific Ocean and 2 manganese nodules from the Atlantic and Pacific Ocean. The basalts and the gabbro probably originated from partial fusion of silicate minerals at great depths in the earth. Defining the crust as the region above the Mohorovičić discontinuity which has a depth of about ... km under the continent and 10 km under the ocean, and the mantle as the region between the Mohorovičić discontinuity and the boundary of the core at 2900 km, basalts and gabbros originate from ... the ... upper mantle. The red clay and manganese nodules on the other hand represent a sampling of lead from a large number and variety of sources on the surface of the earth. This lead may thus represent a reasonable average for the lead ... composition of lead at the earth surface today. Note that the oceanic and basaltic lead have ... similar isotopic composition. This indicates that average surface lead is not greatly different in isotopic composition from lead of deep-seated origin.

The point at 4 ... × 10[9] years represents lead in troilite FeS from two iron meteorites. This troilite contains so little uranium with respect to lead that the isotopic composition of its lead would not be

changed ... in the last 4 ... × 10[9] years, the presently accepted age of the earth. S... (AGE OF). The data from igneous rocks are compatible with the assumption that the ... composition of terrestrial lead 4 ... × 10[9] years ago is represented by the troilite lead. That is, ... 4.5 × 10[9] years ago, with lead of the same isotopic composition as troilite lead, it is possible to select values for the uranium-lead and thorium-lead ratios which will give growth curves for the lead isotopes which fit the observed data quite closely. The calculated growth curves in Fig. 1 correspond to present-day ratios in the source environment of

$$U^{238}/Pb^{204} = 9.3 \text{ (atom ratio)}$$
or
$$U/Pb = 0.18 \text{ (weight ratio)}$$
$$Th^{232}/U^{238} = 4.0 \text{ (atom ratio)}$$

This simple model assumes that the source environment is a closed system in the sense defined above.

It is not entirely clear just what source material the feldspar lead characterizes. The feldspars occur in pegmatites which were associated with processes of mountain building in the past. The lead may have been derived either from lead brought toward the surface from the mantle or from sediments which were buried and melted or partially ... during the process or from both of these sources. However, it has been shown above that lead in rocks of deep-seated origin such as basalt does not differ greatly in isotopic composition from lead in oceanic material which are of surface origin and have undergone ... Thus the curve in Fig. 1 approximates the past variation of isotopic composition of lead in both the outer mantle and in the crustal material.

The isotopic composition of lead in ... galenas has been published. Some difficulty arises in determining the time of formation of galena, as already mentioned ... Accordingly a different method of plotting the lead ... used. If ... is plotted against ... from the curves in Fig. 1 a new curve will result in which each point corresponds to a model age for a particular lead. The model age is the time at which the lead was separated from uranium in the source environment. This treatment may be expanded to allow for varying uranium-lead ratios in the source environment. Assume that a group of galenas originated at a time ... × 10[9] years ago from source environments which all had the same isotopic composition of meteoritic troilite lead 4.5 × 10[9] years ago and which were closed systems with differing uranium-lead ratios. Since the ratio of ... to radiogenic ... will be the same in all the ... regardless of the uranium-lead ratio in the source, a plot of ... for the lead will yield a straight line. Such a line of constant model age and different uranium-lead ratio is called an isochron. Figure 2 shows isochrons for ... lead which was separated from uranium 1, 2, and 3 × 10[9] years ago. Knowledge of the ...

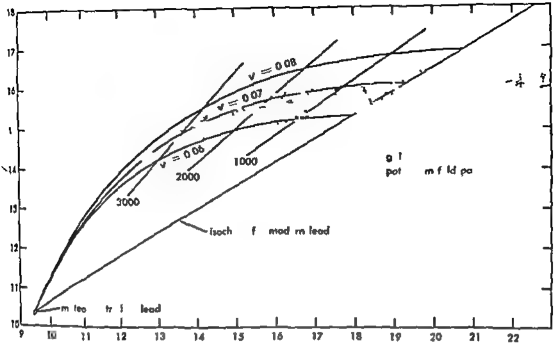


Fig 2 Pb 06/Pb f nct o f Pb /Pb t m l hyp th t c l o c f o m ts. Th for lead fr m g l o d f ld pars Th g f th g owth rve a l l t d f U /Pb earth tek n 4 55 × 10 y rs. D g l l a at a m g cl ed y t m p lb the t m f soch = U /Pb (t m t o) at th pr t le d s pa at

d Pb 06/Pb 04 tio f r y lead will det rm ne ts mod l g

The model ge t b ed n a umb of a s mp- ti ns, the mo t tri gent b g the r qu ement of closed y tem in the u c en r m nt up t th tim of ep r tion of the l d nd b n f n tam, ation f the l ad w th lead f a d ff re t g afte sepa t It is ot pr ing that thes c n ditions ar n t alway m t (se f ll w ng secti n in th artic l on an m l u lead) In fa rable cases m d l gre with th f s p- posedly ntempo a eo igneo ck with ±100 × 10⁶ ye rs, bout the limit f a cur y f th ethod. Th m th d bett r ted f d t gu h ing between tw le ds f gr tly d ff ri g ag r the th n f r determining p e ge F ex ample, t th Appala hian M u t s g l na fr m P ecambri tock at F nklin N.J a m d l ag f bout 900 × 10⁶ y wh le g le a so- ciated with P leozo c k n s e l local t e g e mod l g of 100 t 300 × 10⁶ ye rs The latt galena w p ob bly empl ed d ing me ph f the f rmati n f th App l h n M u t i belt, hile th P e mbri gale s w e f rmed p t the App la hi ns

F gu e 2 ggest that l ad in g l de ed f m so rc nments wh h h e a um l d r tios t d ff ri g greatly f om th wh ch pro- du e th le d f d n gneo o ks Th l d gneou rocks f ll y temat lly bel w th g wt p growth rv f th gal s pe h ps md at ng a l ghtly h gher r um le d r t n the u e for the g l na le d An ther po ibl au e for th s d fference is g en bel w in the e t o n nomal us gal n s Also m re analy es of feld par le ds m t b mplet d t a cert n wh th th p ese t d t p p ly ch acter z ig e s ocks The f ldsp r data a e all f m No th Am a wh le th g lena d t a e f om all c nt e ts ept g A t r ti a H weve there i no iden e f ri tu n fr m e ti nt i n th r i the gal na data It s t iking that th g l n le d f rm u l a l sely d fi ed curve ce they p e t mples t ke m tly at and m n w rld w d scale

Anomalous leads These le d gi e m del ag wh h r lea ly nc rrect. F stance f th mod l ed t det rm ag s c rr ct l ads h ld be f nd t th right f th modern l ad so hr n F g (negat model ag) F gu e 2 doe t the full ge of a mal us leads Pb /Pb r t s as h gh s 93 a d Pb /Pb at s s high s 24 h b e ob erved These xt em c es re howe e A om lou leads a e g e ally h acte i ed by h gh Pb 06/Pb and s m times by h gh Pb /Pb r t os as well Pb /Pb 04 m y t be h gh s nc th abun da e f U is low th t ly n gl gible am nt of Pb h s been mad with pe t t Pb th pa t 2 × 10⁹ y rs N te th t the Pb /Pb urv n F g l n rly fl t o th t tim t rv l

A gn fi nt f at f anomalo l d th t the t p mpo t es c d ably fr m

T bl 2. I otop c composition of l d l a gr lt and oci ted pegm tit

So rce f l d	At m rat os		
	Pl / Pb	Pl 07 / Pl 20	Pb / Pl 20
C tod y	0 3	15 7	48
C t 10 X 10 y rs go	16 4	15 4	30 0
G perth t	18 6	15	39 5
Gra te, pl gnocl se	18	15 5	40 0
P gm t t perth t cry t l	16 8	15 3	36 0

The n sum le d ti f nd for th gra ite g es l l ted Pb 06/Pb a d Pb /Pl t os n the ock 1 05 × 10 y rs ago whi h ag rath r cl ly th the t pic mp ti f l d i the feld p cry t l n a p gm tite Th could i d te that th ro k as wh l l ly p- l um ted a l ed y t m s c n wa form d th respect t r n m Pb nd Pb H w m a m'l r te t f the Pb /Pb r tio h w th t th g a t a n t ha e be n a cl ed y tem f th rium a d Pb The cl e bal n e cal lated f ur um nd le d may th b a id n tal Th fact th t l ad f m both feld par in the granite has an isot p c compo t on cl e t th t of n o d ary mod rn l ad f rthe ggests of external e t m ti n At y rat the lead th feld par i a m lou ltho gh it s n t cl r h the the ur f tam at n w s fr m thi th g a t r out de t S n only e g t ha be t d ed n th m n r there s gu nt th t th data r typ al of gran t s in g ne l Th result r p ent d t ll tr te the types f f rmati n wh h n be bt ned

th t p ese t-d y lead i the gr t c m posit is m lou h g a ng ti e m del age An m l u l d ha be n f u d n a h of two gran tes for whi h the i top c omp t of le d is kn n Th ind c tes th t gr n t s ha e b gh ur m l ad t o than th t whi h e i t th sou e en me t wh h p d ed the le d n ga l as d p t m f ld p rs pl tted i F gs 1 a d 2. Gr tes a p ble f a m lo s lead if mech m ex t f r on tr t ng th le d nt e bod es p gm t tes

Lead isotopes and magmatic differentiation Isot p c lead tud h be n u ed to d m tr t a g eti lation between ev al d ffe e t k typ n th So thern Cal f rni b thol th Gabb t n l t gr od o te a d gra te w e n lyzed Th Pb 06/Pb 20 t ar d f m 18 72 n the gabbr to 19 44 in the gr n t The f th bath l th c r t ly k wn t b 10 y r Tr at g h f the abr ocks s l ed y t ms d l c l ting the top c c mpos t n f th lead 10[8] y ag fr m the u i m l ad at t w f und th t ll of th Pb /Pb t s g with l m t of err at 18 6 to 18 7 Th ium w s n t d t rm ed s th t mil r l l t o f r Pb20 /Pb at o ld t mad The d t tro gly s ggest th t th qu ce of r k rigi nated fr m a large common re ervo r in which the isot pes f le d w re h mogene u ly d tributed [C R T]

B bl graphy F G Houterm ns Das Alter des Urans *Zeit Nat* 2 322 3 8 1947 J L. Kulp *Qua titat i Geochronometry* 1959 National Academy f Scien e *Cosmological nd Geol gical Im pl cat s of Isotop R ti Variati ns* N clear Sci nce Ser R pt 3 1958 G R Tilt n et al I otopic c mp it n and di tribut on f lead u a nium nd th rium in Prec mb ian nite *G l Soc Am Bull* 66(9) 1131–1148 1955

Lead metallurgy

Ext acti n f l d from re and it s b eq ent pur f cati ge erally require pro sing thr ugh thre cla e f m t llu gical pe at n milling smelti g nd refini g Howev mi or to nage of cr d or by rea on of gr de other e o mic n d rat s or b th are hipped for direct m lt g

M ny moder le d ages w re kn wn t anc nt i il zat o a d ha e per i t d d wn th o gh the ce tur es Pr mary w rld c mpti n exceed ng 2,000 000 t ns p year place le d fifth n a t n ge ba i am g the maj r i d trial m t l Se nty fi e pe e t f the w rld le d consumption s withi the ind t ial a e s of Europe and th Un ted St te Bec u f its importance i the field f t an p rt t n (torage batt ies and t tr ethyll ad) chem cal nd ge eral p oce s ng (corro o re tant pip ng and heeti g bea i g a d x nd y r y h eldi g) nd mmu icati ns (c ble sheath g) lead is la s fied as a trat g c mat r l by m t n ti ns *See* LEAD LEAD ALLOYS

Milling (ore dressing) In milli g lead miner l re phy lly freed f m ga gue nd other s ated n tit e ts by dry rushi g a d wet gr d g Lib r ted le d m e l in the r s ltant l ry a e ep r t d by e th r g a ity cla fication r fl t ti n r a i ble mb n t n of both

Th p rt cular mill ng f l ti s a d flow arrang me t mpl yed r rel ted to th h r t r of o e f tre tment (e illu trati n) Compl x s lfide r s of i timate e grai ed mi eral zat on re us lly dry r hed in jaw and gyr t ry r h rs nd wet g nd ball r rod mills pe ated in cl d cir it with cla s fi ati n equipment to a me h adequate f th l b r t of l ad ompo ents fr m g g e and ther a ted min rals The le d m ne l c ntent of the re ulta t deslimed lurry i em ed by elect e flotati and the le d c e t ate p od ct s dew te ed by th ken ing and filtrat on

O c o ally m ll g p ctic s in the t atment of mple o e f e-g ed m n r liz tio such a occur in the Mi s ipp V ll y area m y leat g ty p at o with sele t flot t n empl yed nly f r re d l m ddl ng nd l m prod ct Here the hed e i p p ly ed l ed c cu t w th ib at ng or tr mmel sc ee s d l fi rs. S p at n f th h gh d ty lead

one sample to another The Mi ssissippi Valley leads of Arkansas Mis ouri Illinois Iowa and Wi con sin have variable Pb^{2} /Pb ^{4} ratios which range from 18 5 to 23 Several examples are known of variable isotopic composition in different parts of the same mine Nonanomalous (ordinary) lead on the other hand does not display this variation giv ing almost the same i otopic composition through out a mine or even a geologic province Thus some sort of localized mixing is indicated to be the cause of anomalous lead

An occurrence of anomalous lead at Lake Atha baska Saskatchewan is well studied and will be used to illustrate a solution to the problem Urani nite in a pegmatite in the district is reliably dated by *concordant lead ages at 1 9 × 10 years Pitch blende of hydrothermal origin occurs widely* and isotopic ages all discordant have been determined for 28 of these A systematic study of the di cord ant pitchblende ages indicates that they could have been formed from a 1 9 × 10^{9} year old uraninite by dissolving parts of it 1 1 to 1 2 ×10 years ago and again about 0 2 × 10^{9} years ago transporting the uranium hydrothermally to new sites in veins and losing variable fractions of the accumulated radio-genic lead in the process Three kinds of lead are found in lead ores an ordinary lead and two kinds of anomalous lead Example of their isotopic com positions are given in Table 1

The ordinary galena may be used as a ba is to calculate the ratios of excess or radiogenic Pb^{20} and Pb^{206} the values of which appear in Table 1 It is also calculated that a uranium mineral formed 1 9 × 10^{9} years ago would contain radiogenic lead with a Pb /Pb ^{6} ratio of 0 17 1 2 × 10^{9} years ago and 0 12 2 × 10^{9} years ago Thus the urani *nite pitchblendes and lead ores tell a consistent* story pitchblendes were formed 1 2 × 10 and 2 × 10 years ago from 1 9 × 10^{9} year old ura nium minerals probably uraninite Varying propor tions of highly radiogenic lead separated from ura nium during the formation of the pitchblendes the freed radiogenic lead finding its way into lead ores which now contain anomalous lead The mixing of radiogenic lead with ordinary lead might be ex pected to have varied considerably on a local scale which fits observation

Other occurrences of *pitchblendes together with* lead ores having anomalous lead are the Colorado Plateaus and the Blind River district in Ontario north of Lake Huron These districts are not yet

Table 1 Isotopic composition of lead from the Athabaska dist ict

Type	Atom t			
	Pb / Pb	Pb^{2} / Pb^{20}	Pb^{20} / Pb	R d og n Pb / R d g c Pb^{20}
O d n cy	14 36	14 96	34 49	
Anomalou	40 01	19 36	37 10	0 17
A om lo	43 5	18 7	35 7	0 12

studied as completely as that at Lake Athaba k but a similar mechanism undoubtedly applies Th source of radiogenic lead for the anomalous Mi i ssippi Valley leads has not yet been identified N pitchblendes are observed and the Pb^{08}/Pb^{2} ratios are high along with the Pb ^{6}/Pb ratio Perhaps another mechani m applies

Mention was made earlier of the fact that ign ous leads plotted below the average curve for g lenas in Fig 2 The mode of formation of anom lous leads cited above would tend to produce ju such a result if igneous leads represented unco taminated ordinary lead Highly radioactive mine als like uraninite contain lead with Pb /Pb ratios on the order of thousands and Pb^{207}/Pb *ratios on the order of hundred Mixing this le with ordinary lead produces a lead which will pl* above the curve for pure ordinary lead At lea part of the difference between the i otopic gro curves for lead in ores and in igneous rocks migl be the *result of this effect* It is more difficult recognize anomalous leads when they do not ha negative model age —they can then only be re ognized if regional studies have been made This not the case for many of the galenas hown Fig 2

Lead isotopes in a granite Another applicatio of i otopic lead data to geochemical problems illustrated by a study of the distribution of uraniur thorium and lead i otopes in minerals of a Pr cambrian granite from the Canadian Shield co lected near Tory Hill Ontario *Zircon containe* lead which was entirely radiogenic enabling th mineral to be dated accurately at 1 05 × 10^{9} year Perthite plagioclase and quartz contained lea which appeared to be entirely primary Determin *tion of the uranium lead and thorium lead ratios* i perthite indicated that the ratios were so low th the isotopic composition of the lead would not hav changed appreciably in the last 10 years if th mineral represented a closed system The other mi erals studied sphene apatite and magnetite a had mixtures of primary and radiogenic lead Th composite rock was analyzed for uranium thoriun and lead concentration and lead isotopic compos tion From the age of the rock it is possible t make material balance calculations to study po *sible migration of lead uranium* and thoriu within the rock If each mineral has been closed system then the isotopic composition of lea calculated for the rock 1 05 × 10 years ago fro the present day uranium thorium and lead dat should be the same as that found in the feldspar This comparison is shown in Table 2 It is obviou that some type of migration has occurred Th leads in the feldspars have model ages of about 10 years which suggests that they are contaminate with radiogenic lead and are anomalous A larg *crystal of perthite from a neighboring pegmatit* was f und to contain ordinary lead with a mode age of about 10 years Several galenas with simila lead are also known from the district

from comm pra tice should be noted f exam ple, th pec al zed usage f a tr g he rth for the essentially one-step a t red ct n of the ex cepti nally high grade M ssissipp Vall y m e prod ti and the ubstit t on of an electric furna d conv rt rs fo the us l bla t furnace at the Bol de s op rati n Sweden

Le d m lt r charge p eparat n i clude im portant bl ding and co d t ing operat ns t prepare het roge eou crude ore a d fi e c cen tr te ece pts fo ec nom melting Coar ore siliceo s d ba c fl xes a d c culat g lfur and l d d'lu ts are ru hed sufficie tly f int mate ssociat on with ch g fine Cha ge om po ents are p opo ti ed by riable- peed f der fr m mult ple b f bl nd int a iform, m ture-aggl merated at ter plant feed flow by a riety f arra g ments of p g m ll r tary drum mp t r rm ng t ble f lities

Str ght li e m ch e of the Dwight Lloyd type ar ed f r l ad-o e s nt r ng In the ual double-asting pr t ce fi st-o f ed at bo t 12% sulfu roa ted t 4-5% then d harged cru hed and eturned ft the add t of a mall pe c t g of c ke, fo fin hing on second-o e unts. l altern t ingle-pa s p a t ces all m chi es p odu e fi i hed nte w th ru hed fin shed p od t are lated t ma ta the ulf co tent f aw feed at 5-7% Although mo t pre v ling p act e t lize d wn-d ft ir flow s ces f l p-d aft p a tice fa rable f h ndli g high l d cha g a d fo atta i g high sulfu di xide (SO) g c ntr tio s has ece tly been omm r ally dev loped

Bla t fu ce i g ac ompl hes both a lfur lim na n a d n c p e t f o of ha ge p rt cles int a ll lar truct red te s table f blast furn ce edu tio Charg c mpon ts a e o d zed sulfu t d a SO a d an ut gen s te ng action p p g ted thro gh a lay ed and g t d charge bed by ndu ed i fl w S SINTERING

Blast f rn es e mm ly u ed f the sel tiv red ct of s nte t sl g d bull n com po nt Alth gh th y ary c d bl in d tailed des gn l d bla t f rnace a e ntu lly rectangul wat r j ket d struct 60-120 ft a d 18-22 ft high M lt pl r l t tuyeres ar prov ded l ng th l gitud n l d j t bo th cru ibl b Under n rm l run i g dt u n th furn shaft m ntai ed f ll by fre quent harg g l nte c ta ing bout 10% l ed k Cha g -c lumn bs d tt d th m al f m lten p od ts wl h h e be fused by c mb t on of ke with a bl w th gh tuy b l w A a gr en h rg laye bs de co ter to th upw d fl w of red c g ga ed c ti n and fu on e ac mpli hed w th the f rma tion f m lt n l d bull d zi c b arr g ir n lim b ate sl g In m p t c th b ll i t pped ntt uou ly thr ugh a le d well nd th l g term tt tly th ugh a par t t p t th both d w o t u ly nd the lag and b lli n re then separ ted n he t d t

Comm rci l specifications of efined le d

	Corrod i g le d	Ch m l l d	A d coppe l d	Commo des l er ed l d
S l				
m %	0 0015	0 0 0	0 00	0 00
m %		0 00		
Coppe				
m %	0 0015	0 080	0 080	0 00 5
m %		0 010	0 010	
Comb ed Ag + C m %	0 00 5			
Comb ed A + Sb + S %	0 00	0 00	0 00	0 00
Zi m %	0 001	0 001	0 001	0 00
Iro m %	0 00	0 00	0 00	0 00
Bism th m %	0 050	0 00	0 0	0 150
Le d (by d f f ce) m %	99 94	99 90	99 90	99 [illegible]

n l f rehearth *See* PYROMETALLURGY NONFERROUS

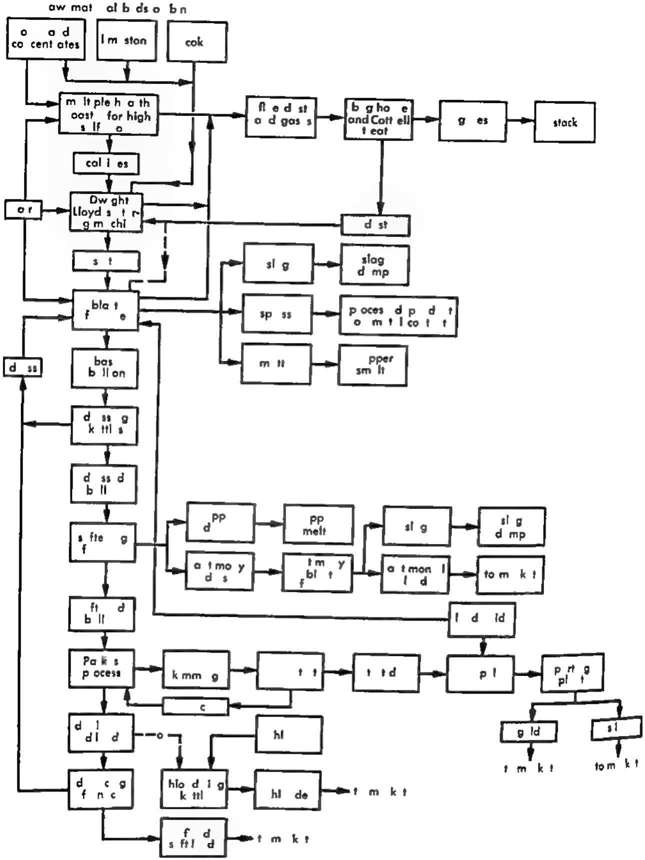
Refining I th pyr met ll rgi l nd electro-lyt c p ocedures are u d for the refini f lead bla t f rnac b lli n f ither e the bulk of th conta ed copper is first rem ed by s mple cool ng d o ng a d sk mmi g Just ab e the freez ng temperatur of the bull on most of the c pper pr ip tates and i sk mmed as matte- per dr A final clean ng ag tat n with eleme tal s lfur followed by sk mm ng ep res the b ll n f r ub eq e t per tio s

M st lead bla t furn ce bull n is suffici ntly low n b muth to perm t ec omi l pyrometallurgi al efi ng in kettle a d re e b ratory fu na es Tin ar ni and ant mo y ar al aged at elevated tem pe tu e by s l ct e ox dati with a r F om the r ult t ft ed bull n ld a d s l er ar em ved by the P rke p o e s wh h util s the select e affin ty fo n and perm u fac sk m m g of th l we den ity h gher melti g all y formed Res d l zi e in the b ll n s rem ed w th u ti (H rr s process) w th chl rin (Bet tert n proc s) o by acu m di tillation If th bull on at th s tage o ta n bi m th n e c of m ket ng specific ti n tre tm nt w th alc um m gnes um alloy (Kr ll Betterton pro s) s nec s ry oth rwi aft r a fi al l ni agitat on with c t c it s a t i t ma k t ble l to blo k 100-lb p g mall var able calki sh pe

Whe the b m th c t nt s s ffic ently h gh, oppe dro ed bulli s c st i to anode and s ele trolyt cally r fi ed by the Bett p ocedu in wh ch p r l d starting cathodes nd n queou l ad fl l at ele tr lyt c ryi g r d amounts f le d nd f e fluo l c acid re us d P ci us metals nd th r mpuriti s c nta ned in the l ad ema n the n d a und l ed adh ent sl me h gh p ty le d s d p ted on c thod wh h at heduled i terv l r rem ed wa hed melted d ca t fo marketing (ee table)

[H E L]

B bl g phy W R Burr w Dev l pm t f a ti us pd ght a nte g p o es P c Aus



Lead smelting and refining

mineral component of the sized feed products is then effected by gravity in heavy medium cones, jigs, or shaking tables. Heavy medium separation has also found limited application in the sink float upgrading prior to subsequent fine grinding and flotation of crushed low grade ores resultant from nonselective mining. *See* ORE DRESSING.

Smelting. Smelting is employed almost exclusively for the actual extraction of metallic lead from its ores and milled concentrates. In lead metallurgy the term smelting generally covers a sequence of three separate operations: charge preparation, blast sintering, and blast furnace reduction. However, certain [illegible]cted deviations

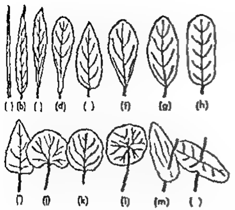


Fig. 4 L f h p ( ) L (b) L n l t (c) Obl l t (d) Sp t l r ( ) Ov t (f) Ob t (g) Ell pt (h) Obl g (i) D lt d (j) R n fo m (k) O bicul (l) P lt t (m) P rf l t ( ) Co te

The b e of th blade m y be cu eate wedge haped blique th t d s f the ba e un qu l e rd te he rt haped ba e w th a c n pic u us n s uri ul t w th a small rl ke lobe n th d f pet le g tt te rrow haped w th p of b l l be t rned nward h tat hal berd h ped with ba al lobes t r ed utw d l p h n es il and partly n e t g the st m.

Leaf shapes A l af m y be l a l ng and n rr w th th ides p ll l or n rly (F g 4) l ol t narr w b t t pe r fr m ba e to ard p t l l t b der t p taper ng t and b se r tul t b o d a d bt e at apex t pe ng t ar ow l o t gg haped bro d est w d b e b t re r of at br d t t d p ell pt c br d t at m ddl a d ta p ring l ghtly t b dly u d d b nd apex bl g mewhat e t ng la w th ne ly stra ght d and ro nded b nd pe delt d tri g l r f rm k dney haped b oade than long o bi ula i ul r or ne rly s p lt t shi d h ped usu lly i ula leaf w th p t l atta hed t n a th c nt of the low r fa perf l t h g the t m appar ntly p ng through t conn t n whi h th ba s f two p p te l a es m t h e f ed a o und the st m

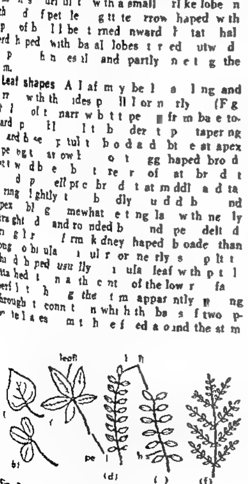


Fig 3 L af types ( ) S mpl (b) T f l te ( ) P l ly po d (d) Odd p t ly mp d ( ) E p ly mp d (f) D mp u d

Leaf types A leaf is simple when it has l ut one bl de compound when the blade i divided i to two r more parate parts alled leaflets trif lio late if it ha thre l aflet (Fig 5) palmately c mpo d if leaflet or gin te fr m a comm n poi t at end of peti le pin ately comp u d if le fl ts are borne on the rachis (nti uat on of pet le) odd p nnate f su h a comp und leaf is te m nated b a leaflet e en pinnate with t ter minal leaflet de omp und (bip nate) if twice omp u d

Leaf venation Th arrangeme t f the ve n or a ular l ndle f a leaf i called venation (Fig 6) There ar three ba i types pa allel the main ein e te ding through mo t f the blade in a pa allel manner as in gr e lilies and most m cotyled n (*see* MONOCOTYLEDONEAE) net the m n ei s b anchi g f rming an irregula net w rk (p n tely if fe therl ke palmat ly if fan like) as i m t d c tyledo s di hot mou f rk d each e n di ding at intervals into small r et s of approximately equal size as n mo t ferns d in ginkg *See* FILICALES GINKGOALES

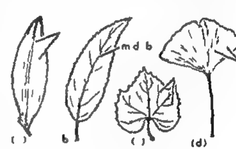


Fig 6 L f t ( ) P ll l (b) N t p t ( ) N t p lm t (d) D hot mo

Leaf arrangement (phyllotaxy) Le ve ce r o st m i definite fi ed rd r a d ng t ape s (F g 7) They s ally app i e f thre ways alt nate if o ly one le f occu t a node opp te f two l e app ar t a node n pp te ide nd whorled (e t ll te) if m r th tw app Alternat l a s a u ually ranged p r lly n the tem if they cur in but tw r w th y are 2 a k d if i fi e r ws 5 r k d

I a l te f fl we s a h flow r ar es nor m lly the a l (armp t) f leaf th leaf h eve s us lly mu h edu ed i and i ll d a b ct Th b act s d to subtend the fl w r *S e* FLOWER (BOTANY)

Leaf surface Su fac s f l a e p vide m y cha et u ed i dent fic t n A s rf ce is gla ll f it mo th f e f m ha r gl c f d w th a wh t h w xy m t ial r bl m c b us fr gh o h r h t th t u h p be ce t g l t m f h ir ne of a y k d ppo ed t gl bro p b *rul nt* with ry fi e d w l k hai s i m nto w th matt d woolly h ll us w th l g ft shaggy h h sut d w th h t, e e t tiff h s a d h p d d n w th b tly ha hly t ff hair

tralasian Inst Mining and Met 162–163 267–292 1951 T R A Davey Vacuum dezincing of de silverized lead bullion *AIME Trans* 197 991–997 1953 D Evers Debismuthizing by the Kroll Betterton process *Z Fr bergbau u Metallhut tenu* 2(5) 129–133 1949 H E Lee and D In gvoldstad The modernization of Bunker Hill pre sintering practices *AIME Trans* 206 1469–1473 1956

Leaf (botany)

Leaves are modified as aerial appendages which de velop from stems at nodes (stem joints) and usu ally have buds in their axils *See* Bud (botany) Stem (botany) In most plants leaves are flattened in form although they may be needlelike as in pine scalelike as in arbor vitae or nearly cylindri cal as in onion Leaves usually contain chlorophyll and are the principal organs in which the impor tant processes of photosynthesis and transpiration occur *See* Chlorophyll Photosynthesis Plant water relations of

Leaf parts A complete dicotyledon leaf (*see* Dicotyledoneae) consists of three parts the ex panded portion or blade the petiole which sup ports the blade and a pair of stipules mall ap pendages attached at the base of the petiole (Fig 1) Stipules may be green and bladelike as in pea coarse rigid spines a in black locust sheaths as in smartweed tendril like as in greenbrier or mere temporary hairs or bristles as in lespedeza Leaves that have a blade and petiole but no stipules are said to be exstipulate Some leaves have no ap parent petioles and are described as sessile The leaves of gra ses have neither petioles nor stipules the blades are attached to the tem by an encir cling sheath (*see* Grass crops) At the junction of the sheath and the blade is a collarlike structure called the ligule In pines needlelike leaves are borne in fascicles (clusters of 2–5 rarely 1) at the ends of short dwarf branches (*see* Pine)

Leaf margins The margin or edge of a leaf may be entire (without indentations or teeth) ser rate (with sharp teeth pointing forward) or serru late (finely serrate) dentate with coarse teeth pointing outward or denticulate (finely dentate) crenate or scalloped with broad rounded teeth un dulate with a wavy margin incised cut into irreg ular or jagged teeth or segments (if segments are narrow and pointed laciniate if directed back ward runcinate) pinnatifid deeply pinnately parted (featherlike) di ected cut into numerous lender irregularly branching di isions (Fig 2)

When the blade is deeply cut into fairly large portions these are called lobes The degree of uch lobing may be de ignated by the following terms lobed with sinuses usually not more than halfway from margin to midrib (mid ein) or ba e and with lobes and sinuses more or less rounded cleft when inci ions extend halfway or more from margin to midrib and especially when they are sharp parted cut so deeply that the sinu es extend almo t to the midrib or ba e divided cut entirely to the midrib which makes a leaf compound

Leaf tips and bases The tip of a leaf may be acuminate gradually tapering to a sharp point acute tapering more abruptly to a sharp point l tu e blunt or rounded tip truncate eeming to l e cut off square or nearly so emarginate decid edly n tched at tip but not lol ed mucronate abruptly tipped with a small hort point cu pi date end ng in a sharp rigid point (Fig 3)

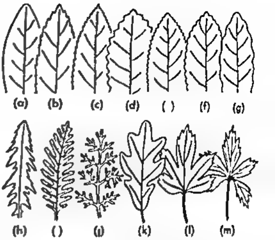
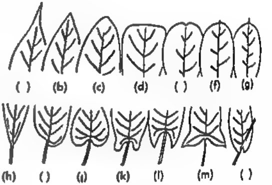
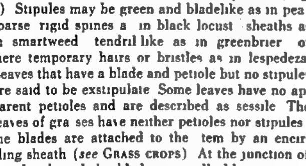


Fig 2 Leaf marg ns (a) Entire (b) Se rate (c) S u late (d) Dentate ( ) D nt c l e (f) C enate (g) Un dulate (h) Inc ed ( ) P nnatif d (j) D ssected (k) Lobed (l) Cleft (m) Part d



F g 3 Leaf t ps and bas s (a) Ac m te (b) Ac te (c) Obt s (d) Tru cat (e) Em rg t (f) Muc at (g) C p date (h) C eate ( ) Obl q e (j) Co d te (k) Aur culate (l) S g ttate (m) H st te ( ) Cla p g



F g 1 L f parts (a) Compl te leaf (b) E st pulat leaf (c) Sess l leaf (d) Le f of g a s ( ) Det l f p t on of (d) (f) N edl l ke l a es of p e

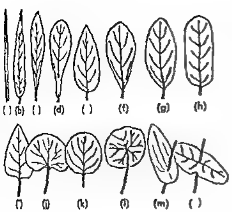


Fig 4 L f h p ( ) L (b) L ol t (c) Obl l t (d) Sp t l t ( ) O t (f) Ob vat (g) Ell pt (h) Obl g (i) D lt d (j) R f rm (k) O bicul (l) P lt t (m) P rf l t ( ) Co t

The b e f th bl de m y be cu eat wedg haped oblique, th tw d s of th b e n equ l c d t h art h ped b e with co pic i ulate with a m ll ea like l be n either de of p t le agittat rr w h p d w th pa r f ba al l bes turned a rd h t te hal be d sh ped th b l l b tur ed ot twa d l y g h ile d p rtly a t g the tem

Leaf shapes A le f may be l n r lo nd are with th des p all l r n rly o (F g 4) l lat n r w b t t pe g fr m ba e to ard pe bl n e l te br d t p taper g t d ba p tul t h o d a d bt at ap x l pe ing to b e t gg hap d b d est t d b se b te re of at br ade t t ard p x ell pt b dest t m ddl d t pe ing l ghtly t b dly r d d ba nd pex bl g, som what e ta g l r w th e ly straight des and nd d b a d p d lt d triangul r nif rm k dn y h p d br ad than l g bi lar ci l o n a ly p lt te sh ld h ped u lly a a l le f w th p ti le m bed at ne th nt f the l we f pe f l te h ing th t m appa tly p g thr gh t n t in whi h th b s f two p po te l es em t h e fu ed ar u d the st m

Leaf types A leaf is s mple when it has b t one blade c mp nd when the blad is d ided int t o or more ep rate part called leaflet trifol olate if it ha three leafl ts (Fig 5) palmately omp u d if leaflets or g nate fr m a comm n point at end f peti le pinn tely comp d if le flet are b rne on the rach (c nti uat n of pet ole) odd p nnate if u h a comp u d leaf is te m nated by a leaflet e en pi ate without t r m nal leaflet d c mpou d (l ip nnate) if twice mp u d

Leaf venation The arrangement of the vein or a cul r l undles of a le f i called e ati n (Fig 6) The e re three ba ic types par llel the ma n n ext nd ng thr ugh m t of the blade in a par ll l manner as in gra e l l e and mo t mon otyled n (s e MONOCOTYLEDONEAE) net the m in in br n hi g f rming an irregul r net work (p nn tely if f th erlike p lmately if fan like) as i m t d cotyled s dichot mou f rked ch ve n di ding at i tervals int sm ller em of appr ximately eq al si e s in m st ferns and i g nkg *Se* FILICALES GINKGOALES

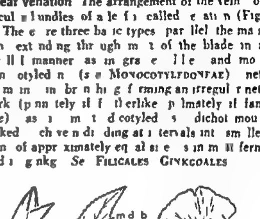


Fig 6 L f t ( ) P ll l (b) N t p t ( ) N t p lm t (d) D h t m

Leaf arrangement (phyllotaxy) Lea s oc u n a t m n a d fi t fi ed rde acc rd ng t peci (F g 7) They us ally pp e f thr w ys lt n t f o ly a l af oc ur at a d opp ite f two lea es appear t a nod opp te ide nd wh led (ert c ll te) if m re th n tw appe Alte nat le e are u ally a ged p r lly n the stem if they oc ur in but two ws th y a e 2 ked if n fi e r w 5 nk d

In a l st r of fl w ach fl we a ses n r m lly i th a il (armp t) of a l f th s leaf h w e s u lly mu h ed c d in i nd alled br ct The b ct i s d t subt d th fl we *S* FLOWER (BOTANY)

Leaf surface S fa e of l p de m ny char t d n de t fi at A s fa e i gla b f t mo th f e from h glau s f d with a wh t h w xy mat al o blo m c b s if r gh ha h to th t h pube ce t g l te m f hair of any k d a pp d t glab u pube ul nt w th y fi d w l ke h t m nt e with m tted woolly h llou w th l ng oft, h ggy h rs h te o ed with h rt s t t ff ha a d h p d d with b tly h r hly i ff ha

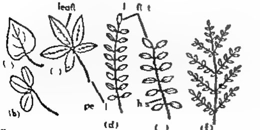


Fig 5 Leaf typ ( ) S mpl (b) T f l t ( ) P l mat ly compo d (d) Odd p t ly mp d ( ) Eve p t ly d (f) D mp d

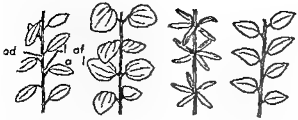


Fig 7 Leaf arrangement (l to r) alternate opposite whorled alternate 2 ranked

Leaf texture The texture may be described as succulent when fleshy and juicy hyaline if thin and almost wholly transparent chartaceous papery opaque but thin scarious thin and dry appearing shriveled and coriaceous tough thickish and leathery

Leaf duration Leaves may be fugacious falling nearly as soon as formed deciduous falling at the end of the growing season (*see* DECIDUOUS PLANTS) marcescent withering at the end of the growing season but not falling until toward spring or persistent remaining on the stem for more than one season on the plant thus being evergreen *See* EVERGREEN PLANTS PLANT ORGANS PLANT PHYSIOLOGY PLANT TAXONOMY [N A]

LEAF ANATOMY

In a true leaf the veins are continuous with one or more vascular strands of the stele the primary vascular cylinder of the stem (*see* STELE VASCULAR BUNDLES) The strands that connect the leaf with the vascular system of the stem are the leaf traces A part of such a leaf trace passes through the outer stem tissue or cortex (*see* CORTEX PLANT) Above the point of divergence of the leaf trace from the stele an interruption of the vascular tissue occurs and this parenchyma filled area is the leaf gap (*see* PARENCHYMA) Although there are flattened leaflike structures among the lower plants such as algae liverworts and mosses these are not true leaves because they lack a well defined vascular system (*see* ALGAE HEPATICAE MUSCI) Some of the primitive vascular plants have microphylls (small leaflike organs) but these have a single unbranched leaf trace and there is no leaf gap in the stele

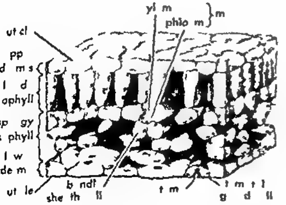


Fig 8 Three-dimensional diagram of a bifacial mesophytic leaf

Internal structure in relation to function The foliage leaf represents the chief photosynthetic component of most vascular land plants (Fig 8) Although leaves vary greatly in size shape and complexity they consist of the same three tissues as does the stem dermal or surface layer vascular including the xylem and phloem or conductive tissues and the ground tissues parenchyma and sclerenchyma (*see* EPIDERMIS PLANT PHLOEM SCLERENCHYMA XYLEM) In the leaf however the arrangement and modifications of these tissues have obviously evolved along lines favorable for photosynthesis within various habitats and climates (*see* EVOLUTION ORGANIC) The ground tissue or mesophyll of the leaf is primarily chlorenchyma that is tissue with cells containing chloroplasts (*see* CELL PLASTIDS) With a maze of intercellular spaces in the chlorenchyma each cell is exposed to an internal moist atmosphere The sheetlike distribution of the chlorenchyma in the blade exposes each individual cell to light The vascular tissue is an intricately branched network of veins embedded in a midplane within the chlorenchyma

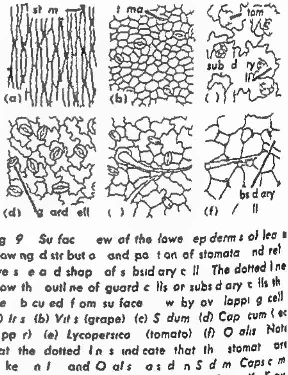


Fig 9 Surface view of the lower epidermis of leaf showing distribution and pattern of stomata and relative size and shape of subsidiary cells The dotted lines show the outline of guard cells or subsidiary cells that are obscured from surface view by overlapping cells (a) Iris (b) Vitis (grape) (c) Sedum (d) Capsicum (pepper) (e) Lycopersicon (tomato) (f) Oxalis Note that the dotted lines indicate that the stomata are sunken in Iris and Oxalis raised in Sedum Capsicum and Lycopersicon and flush in Vitis (From K Esau Plant Anatomy Wiley 1953)

Every cell of the mesophyll therefore is relatively close to mass movement of water and solutes through the xylem and phloem of the veins—water and mineral ions move chiefly through the xylem dissolved foods chiefly through the phloem *See* PLANT MINERAL NUTRITION OF PLANT TRANSLOCATION (ORGANIC SOLUTES) The nongreen compact epidermis is similar to the epidermis of stems and other exposed plant organs (Fig 9) The stomatal guard cells alone among the epidermal cells contain chloroplasts and the stomata constitute openings in the otherwise continuous epidermis the

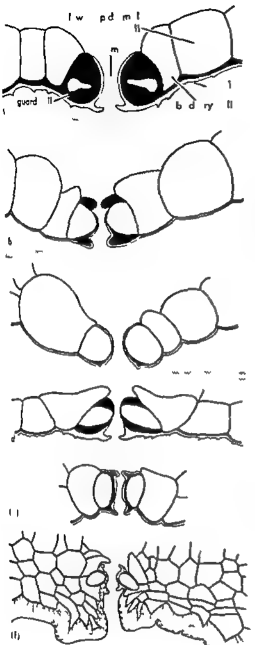
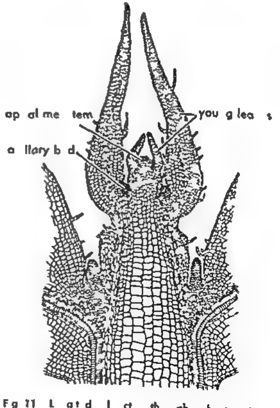


Fig 10 Tra se t f t m t th l w pd rm f l av h w g d g f d d unk p rt f th g d ll l t t b- sd ry p d l ll N t th t th t l f m p ruso l dg t th t m t l p g ( ) P (pe h) (b) P st (p rs p) ( ) S l m (potato) (d) H d (E gl h vy) ( ) M (b) (f) E (Ad pt d f m K E Pl t A t my W ley 1953)

mata The open ng and cl sing f stomata within the epidermis f many lea es re ult e sentially from light and temperat re en t ity Thu dur i g p ri d f rapid phot ynthe when diffu i n pre re grad ents f ga (between the internal spaces a d th extern l atm phere) are teep the t mata e op Alth ugh water l i h gh dur ing these p riod water con erved at other times whe the st mata are cl ed The intercell lar sp ce f th me phyll are lined with a th n fatty film mil r to the cut le i comp iti Th film n d bt i l bit ap r tion to me extent from the mes phyll ell t the i tern l spaces

In well differ tiat d bro d le the chloren hyma con i t of two ntr ti g ti ue y tems pal de d pongy me phyll P lisade ells are typically c lum r i hape l ely p ced and ori ted parallel with e a ther but with their l g t d meter at right angles t the f ce of the blad Sp gy me phyll cells n the contrary e a t l sh ped and are o iented w th the l ng t d m ter chi fly in the p rad rmal pl ne (the pl ne f the bl de p rallel with the ep dermal l y r bl d urf ce) The great r p rt of ph to- y the o ur with n the pal ade ells wh r th hl ropla t are m st numer T a fer f w t r and lute fr m li g cell t l i g cell nd b twee v ns o ur chi fly th o gh th

ll of wh h e d by w y f tty c t l (F g 10) Th the p d rm t ansl c t t p oofed B t part lly p f ated g th gh h h l ght p t t but th gh wh h th d ff n f w t p r d ga l m ted These g se p c p lly th gh th to-



Fg 11 L g t d l ct th gh h t t p (t m l b d) h w g t g th d l pm t f f l g l f m th p l m t m (F m E N T H C S mp d L H T ff y T tb F B t y d H p 1953)

spongy mesophyll and dermal tissues becau e these are the tissues having consistent lateral contiguity There is only limited lateral contiguity among the palisade cells

Among leaves in which guttation (s cretion of water from the tip and margins of leaves) i known to take place pecialized tissues called hy dathodes occur near the vein endings in the blade tips and margin Mo t leaf movements are caused by irregular growth rates (see PLANT GROWTH) but certain reversible movements are caused by changes in water content of cells within pecialized structures such as the pulvinus (a swelling at the base of the petiole) Ergastic substances (waste products and crystals of mineral elements) accu mulate in various living cells of foliage leaves With leaf abscission (fall) these wa te materials are eliminated from the living plant

Leaf development Each foliage leaf whether simple or compound arises as a leaf primordium (a protrusion compo ed of relatively superficial cells) at the apical meristem or region of cell divi sion at the shoot tip (see MERISTEM APICAL) As the leaf primordium elongates and thickens by nu merous cell divisions a primordial axis form which later differentiates in part as midrib and petiole (see MITOSIS) On either side of the axi marginal meristems containing marginal and sub marginal initials give rise to a number of cell lay ers from which the blade tissues differentiate

In woody plants tiny folded leaves with recog nizable shapes can be distinguished in winter bud These young undifferentiated leaves develo, n buds during the growing sea on preceding the win ter Thu in the spring as the buds open and the bud axis elongates forming the new twig the tiny leaves unfold and expand to their mature size within a few days Although during this surge of spring growth a limited amount of cell divi ion oc curs the major activity is concerned with cell en largement and differentiation In ome woody plants additional leaves arise and mature during the same growing eason Foliage leaves con mainly of primary tissues (tis ues that arise from the apical meristem or the embryonic t m tip) and except for some ferns and a few seed plants

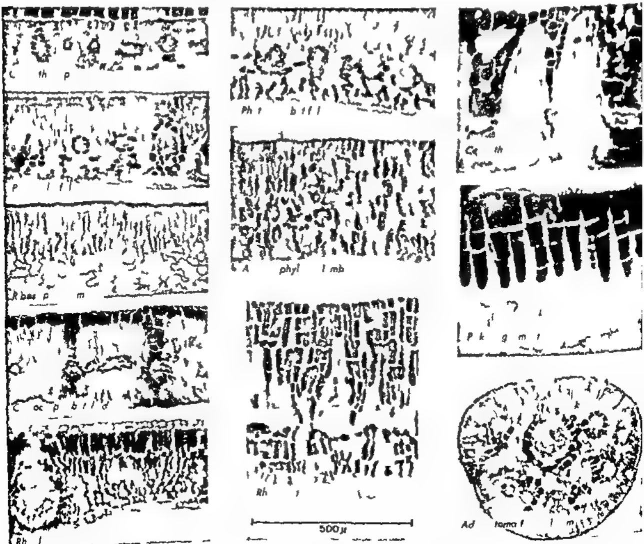


Fig 12 Trans erse sect ons of th xe omo phic leaf blades of ele en spec s of e e gr en chapar al shrubs f om the Santa Monica coastal mount ra ge of Cal fo n a Although the mesophyll of most of these lea es i p edominantly p lsade the st uct l b f c al fo ele e and cent c f on Note the f t vely th n epide mal lay s

ha e determ ate growth (as cont asted with co tinued gro th of a tem) Le es of ome ocotyled ns complete terminal g owth and e n in w dth but they c t nue to grow for a d rable time f m m r tematic cell in the l b se (F g 11)

e f absc s n occ s t th e d f a single wing easo n decidu s woody pla ts Am g rgree spec es howeve the le s pers t gh se al growing as s Leaf ab cis ion urs ithin a defi te zo e near the ba e of the le. Aft o somet m d i g ab ci n a f sube in and a gumlike sub tance is ecreted the l g ell forming leaf c o cicatrice A corky ti s e pe iderm then f rm by l d n der the at (se PERIDER I) th n the l f s are b dle scar wh h h w ere the sc l r b dles ab c s d Ab ci sion the t p les d h act lly o c ery early th growi g se on Leaf ars bundle s d st pule ars are di t gu hing f at res of m c mp rt nce

Factors that influence structure B th he ed ty d en ment ar respon ble for th great ar m l f tru t e Alth gh he d ty ac o ts a gr t array of forms th pla t u ually h m of th tru t ral feat s o at d with th h t t (e vi o m nt) Striki g s m l mes e bserved am g un el ted but ec l gically c rgent pl t f rms (sp th t ha e e l ed sim ant es f f rm nd beha o with a g en h b t) Th r f ot all t tural ch cteri t effect phyl g tic el ti hip that s, relat ups th t i d t m l r evol tio ry h t ry Alth ugh e l g c l eq len am ng u ated spec s n t f lly de stood some g e l f f rms are c mm ly ci ted w th erta ell-d fi d e vi m nts h b t t For e am le, m i t bo l fo e ts e dom ted by tre th eedl l k eve g een le e t mpe ate r ny ep s, by trees with br d d ciduo l es Med terran lm tes r domi ted by hrub and mall trees th h d br d eedl l k l e Perhaps th l g al equ le ts m t d fficult t d t d a th de ert h ubs Some f th hrubs h m ll u fy li ry ly de d s le es a f w ha m ll rn h d eve gr lea es and t'll othe s s c ul nt a d p ct llyl g

X phytes and hyd phyt s r th t rm used for pla t that n rm lly gr w i dry (x ri) a d moi t h b t ts, re pe t ely Mo t pl t th t grow in tempe t cl mat s a e m sophyt s f e mpl the comm n cr p pl nt s d d t be m hytes h h a i termed t betw n th o- phytes d hyd phyte th m t e req i ment Th h m y t m al st d f pl nt gr g in ext me and t mp r te hab t cert n truct l fe t es h e bec me k wn m r phic, mesom ph c, r hyd m phi S e ome f th t t al f t q t t t u h n p g d th k e f c i cl o s de- gr es f m phy r hyd m phy n b b- served in otherwi e me m rph c pl nts F r e ample am g le e on typically mes m rphic pla ts th e at the higher le els f in erti n on the pla t u ally show ome xeromorphic tend encies as compared with lea es at lower le el and the leaves that h e devel ped in full sunlight are more xeromorphic tha the that devel p in th h de Among lea e of m som rphic plants grow i g in dry and moi t hab tat the leas f pl nt from the d ier habitat h w a tendency tow rd xeromorphy Xe m rphic fe t es are n t al ays e ly interpreted S me a pects of xeromorphy are ass c t d with higher r ther than l wer rate f transpirat and xerom rphy is characteri t c of pl nts grow g in wet peaty il as w ll as i dry hab tat (Fig 12)

Dermal tissues Ep dermal cells are typically tabular in h pe but the surface and inner wall may be flat rou ded or p pillo e (with nical p tuberance) and the ant cl l wall (wall at right gles to the surfa) are flat und late (wavy) The surfac hapes f epidermal ells re polyg l amebo d or nuo Ep derm l c ll the low surface re us lly smaller and more sinuo th n are the pper ep dermal cells Cell of h de lea es and hydr m phi leave are m e ous th n th f s lea es and xer morphi lea es

The upp or l wer ep derm s m y cons t f m ltiple l vers It is t rmed multiple ep dermi f all f cell arise f m the pr t derm (the sur face me istem fr m wh ch the epid rmi is de- ri ed) If the s bderm l cell ar de i ed fr m a int or m ist m the ubderm l t su termed hypodermis S bdermal ell re usually fewer i mb d l ge n v lum than a e the accom p ny g ep dermal cell a d th y t nd t be l s riable i hap (u lly isodiametri o elon gated polyhedr) The mult ple epidermis a d hyp dermi are h ra ter tic f tr p cal evergreen lea es Dermal t sues compo a 20-30% f the to- tal bl d lum in mes m ph c lea s b t om xer m rph c le s h v ry hallow p de mal laye

Th le th t e s the ut r su face of th ep d rm i comp d f aryi g m t of utin d p t n (ee PECTIN) The outer w ll re not only c t cula i d (e ed by l y f cut n) but in dd t n they are ut ized (mp egn t d with cut) R d l piderm l w ll r l o f e- q e tly tin d Hea ly t n ed epidermal c ll t nd t be ather un form nd d metr c in hap

Th st mat m y be flu h with d) ce t ep d r m l ll th y may b ra ed r ke Stom t re l fi d hefly p n th s of h pe and e t t n f s b di ry c ll (cell djac nt t th gu d ell) In d s t l blad s f meso- m rph lea es d t p c l ev rgr en lea e th t m t c fi ed p i cip lly t the l w epi d m l fl t g le es f w t r pl nts well de- el p d t m ta f u d ly with the upp r p d rm l x mo ph i l t i l l a es d y

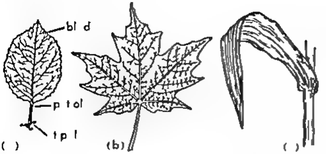


Fig. 13 Simple leaves illustrating the arrangement of prominent veins. Blades (a) and (b) have the netted vein arrangement. (a) Pinnately veined leaf of apple. (b) Palmately veined leaf of sugar maple. (c) Parallel venation of a corn leaf. (From C. L. Wilson and W. E. Loomis, *Botany*, [illegible] ed., Holt, 1958)

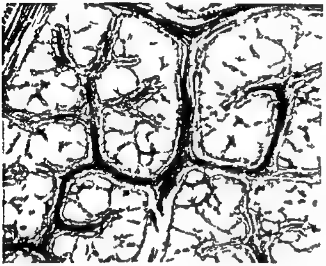


Fig. 14 Photomicrograph of the intricate network of minor veins and associated spongy mesophyll of *Ficus elastica*. The tissue section was cut from a midplane of the blade parallel with the surface of the leaf.

lindrical leaves, the stomata are distributed over the entire surface. Stomatal frequencies have been reported for a number of species, and they range from 14 to 1540 per mm².

An epidermal appendage (trichome or hairline structure) may be a simple outgrowth of an epidermal cell or a unicellular or multicellular structure. The separate cells may be relatively undifferentiated or secretory (glandular) in nature (*see* SECRETORY STRUCTURES, PLANT). Idioblasts (cells markedly different in shape or function from other cells within the same tissue) and cells with crystals and other inclusions, as well as trichomes, are constant features of certain species.

Mesophyll In bifacial leaves (those with dissimilar tissues above and below) the chlorenchyma consists of one or more layers of palisade cells near the upper (adaxial) surface of the blade and one or more layers of spongy mesophyll cells in the lower (abaxial) portion. There is relatively little lateral contiguity among the palisade cells, although some of the cells are tangent along portions of their length. Palisade cells subtend epidermal or hypodermal cells and are contiguous with the spongy mesophyll cells below. In most mesomorphic leaves the spongy mesophyll includes large intercellular spaces, and its cells are oriented chiefly within the paradermal (horizontal) plane of the blade. If the cells are branched, one or more arms are extended within the paradermal plane. In the midplane of the blade, which includes the intricate system of minor veins, the spongy mesophyll is in the form of continuous nets of living cells closely integrated with the small veins. The intercellular space system in the entire mesophyll tissue of measured leaves accounts for 35–71% of the entire blade volume. Although the greater volumes of space are within the spongy mesophyll, larger internal surfaces (cell wall surfaces lining the intercellular spaces) are exposed within the palisade mesophyll. Among measured leaves the internal exposed surface is 4.6–31 times as great as the external blade surface of the same leaves. In a few species the palisade cells are H-shaped or U-shaped; in other species the columnar cells are laterally contiguous by adjoining protuberances. The number of layers of palisade may vary in leaves on the same plant. In isolateral blades (blades with similar tissues on both sides) the mesophyll consists entirely of palisadelike cells, or palisade cells occur in both adaxial and abaxial portions on either side of a midregion of spongy mesophyll. In the all-palisade leaf the cells in the midregion of the blade have some lateral contiguity. In some foliage leaves the palisade and spongy mesophyll are not highly contrasting tissues. The degree of contrast between the closely spaced vertically oriented palisade cells and the more diffusely spaced laterally oriented spongy mesophyll cells varies with the species as well as the environment.

Vascular system The two main patterns of venation (arrangement of the prominent veins) in broad foliage leaves are netted and parallel (Fig. 13). Most dicotyledons have netted veins and the most prominent veins are arranged pinnately (one midvein with secondary veins diverging from it) or palmately (several large veins spreading out from the base of the blade). Among the larger veins an intricate network of minor veins is well distributed within a median plane of the mesophyll (Fig. 14). Most monocotyledons have parallel veins (main veins arranged longitudinally within a linear blade) interconnected by smaller veins.

The primary and secondary veins along with associated mesophyll tissues form prominent ridges (vein ribs) on the abaxial side of many foliage leaves. The midrib region of such leaves is similar in structure to the petiole; it consists primarily of one or more vascular bundles of xylem and phloem (the xylem on the adaxial side) and supporting tissue. Xylem or phloem fibers or both may be present, and some of the ground tissue on either side of the vein proper may be in the form of collenchyma, a tissue consisting of elongate cells with unevenly thickened walls (*see* COLLENCHYMA). The parenchyma associated with the major veins has rela-

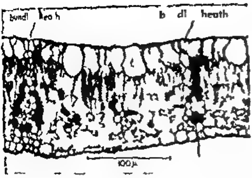


Fig 15 T rse s ct th gh th b f l fol ga leaf f F y mo howing w th b ndl sheath t ns.

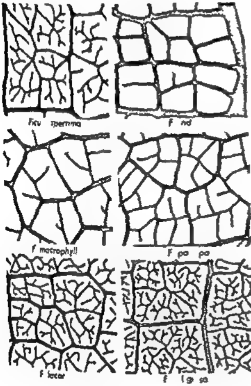


Fig 16 Diag m f m p tt rn f specie f F Th t ppled th e w th b d' sh ath xt n Th s p t d by l d broad F mb dd d th me phyll d l k b ndl shea h e t

by ly f w hl pl ts The epiderm l ell n h thi g th m jor e s f y ntly elo g t th h s ax

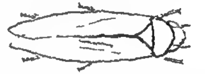
Th m n s that a mbedded i the me o-phyll con t f xyl m nd phl m l m nts cl ly surr ded by b dle h tl h th of thin a led p enchyma cell (F g 15) There n pport tis bo t th m i Som et end g en t f gle t h d (yl m lement) phl m nd a b dl h th B dl h th ry i mpl x ty a d may h ly few

no chl roplats Howev ı ı a few xe om rphs the bundle heath the principal chl r phyll bear ı g t ue In ma y d tyled ns l ndle h ath te on (panels of p enchyma cells) e te d fr m the b ndle sheath to ne r both ep d m l layer S ce th l ndle h ath ext ns u ually ha e l ttl chl rophyll they appear like p rtiti n betwe n block of ph t ynthetı m sophyll within the blade B dl heath ten ı ns e of frequ nt o r e ce ı d cidu u f l age l a e The min r e amify thr ugh the m dplane of the me- phyll ariou mple p ttern (Fıg 16) In the p ■ de mal pla ■ ınter n ecting minor ein may f rm l ed n t or they may be dendriform (ar anged n intri at bra ch ng y tem) with nu me u e n nding [J P]

B bl g aphy Se PLANT ANATOMY

Leaf hopper

Any of umer u spec es f the insect f mily Cicad ll dae o der H moptera This ı e y la ge family and incl des an uncert ■ numb l spe es f m ll l nder ı ect f eq ently trik ngly ma ked in brill nt c l rs They re dist g hed from m lar f m l l y the d ı l le r w f spines the h d t l a their w ng meet in a deeply n erted V a d t nd b yo d th tip of the bdo- r e the eyes ar ually large



R l f hopp *Emp a* l gth t ¼ n (F m E L P lm *F ldb k f N t l H st ry* McG w H ll 1949)

Alth gh each pe es ı ge er lly r t icted n its h b t t and the pl nt n whi h t f eds, ther a e leafh ppers ı irtually ■ ery s t at whe pl nt g ow

S al a e f e on m c imp rtan feed ng ar ty f fi ld nd gard rops M ny k w s h p hoot l e n cotto *S* HOMOPTERA [J D B]

Learning theories

A fi ld f psy h logy embr ci g hab ts kill mem es a d p bl m sol ng incl d g the qu t on r te t nd t lizat o Theo ies f learn g ha b e e l ed by psychol g t w k g th timul e po c d t ed r flex, *o* ept d th g it r awar es n ept *Se* MEMORY PROBLEM SOLVI G (PSYCHOLOGY) SENSORY LEAR ING VERBAL LEARNING

Stimulus response concept Cond t n ng e p me t h y lded rt n l wful r l t h p u h a l bl tım *t rval* betwee t m l effe ts of ate l p nt t p n qu t ■ ta e us ry f esp t ngth foll w g edu ti th o gh ext n t n p oced ■ and so

on It is assumed that these relationships can serve as the basis for predicting more complex habit phenomena such as those involved in learning a language or operating a typewriter Application of conditioning principles is not solely by analogy but the effort is made to predict effects that superficially are unlike the relationships used in prediction For example the fact that items in the middle of a list are more difficult to memorize than items at the beginning or the end is not reflected in simple conditioned reflex experiments Yet it is possible to use relationships from these experiments to predict this fact C L Hull was a leading theorist in this field and his proposals have been extended and modified by N E Miller and K W Spence

Hull recommended the hypothetico deductive method That is he preferred to set up a small set of postulates which are relationships from simple conditioning experiments usually empirically established From these he proceeded to deduce more complex phenomena as theorems These theorems if confirmed by experiments tend to confirm the postulates In order to simplify the total number of postulates he departed somewhat from purely empirical relationships in order to infer intervening variables as simplifying constructs These intervening variables given such names as drive or habit strength lie between the observed stimulus or input variables and the measured response or output variables Hull's most basic formula became

$$_{S}E_{R} = H_{R} \times D$$

in which each of the terms is an intervening variable Thus $_{S}E_{R}$ is the inferred reaction potential which if above threshold leads to the measurable overt response R to the stimulus S This reaction potential is some multiplicative function of habit strength ($_{S}H_{R}$) acquired as a result of repeatedly rewarded experiences and the motivational conditions or drive (D) active at the time Thus habit is activated into behavior only when the drive conditions are adequate Habit strength depends upon rewarding circumstances known as reinforcements The complete formula for response evocation includes a number of factors in addition to habit and drive for example stimulus intensity and the amount of reward used in prior reinforcement

B F Skinner also bases his interpretations on the data from conditioning experiments and accepts reinforcement as the basic operation for response strengthening He takes a more positivistic approach than Hull but disclaims the notion of intervening variables and refuses to use the hypothetico deductive method He has been successful in demonstrating a great deal of lawfulness in learned behavior using a variety of schedules of intermittent reinforcement that is reward on only a predetermined fraction of the trials In Skinner spot pecking experiments with pigeons the bird receives food reinforcement following pecking at a target but the food is delivered only once every 10 minutes The target at which the pigeon pecks changes slowly so that it serves as a kind of clock The pigeon begins to respond 7–8 minutes following prior reinforcement and is responding more than 10 times per second by the time food reinforcement is delivered (Fig 1) While his basic work has been on lever pressing by rats and spot pecking by pigeons Skinner has had some success in applying his analysis also to verbal behavior school room learning and the behavior of psychotic patients

There is also a nonreinforcement variety of learning theory according to which the basic relationship for habit formation is merely the contiguous presence of a stimulus with a response (Fig 2) A sophisticated theory derived from the contiguity principle has been proposed by F R Guthrie and given mathematical expression by W K Estes and C J Burke The mathematical model is based on the assumption that the learner is sensitive to some fraction of the total stimulus complex available to him and that this fraction becomes attached or conditioned to the response that occurs Hence as a response is repeated an increasing fraction of the possible stimulus components will have been conditioned to it so that the response becomes increasingly probable on later trials The model describing this increasing probability makes use of the mathematics of set theory and is known as a stochastic model (see STOCHASTIC PROCESS) The model and its parameters are logically specified and the parameters are then empirically derived by curve fitting (see BIOMETRICS BIOPHYSICS MATHEMATICAL) Considerable success has been achieved especially with relatively simple probability learn

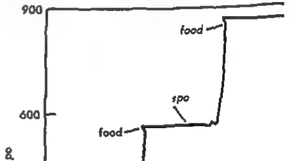
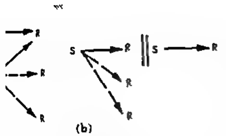


Fig 1 Control of responding by reinforcement (Adapted from C B Ferster and B F Skinner Schedules of Reinforcement Appleton Century-Crofts 1958)



(b)

II f m t d f ■ t S-R th o- 1N e f rc t S-R th ry C dit ed t m ,) ke R th th R R b c th r n (S) c I t c th p f S is called ng ty th ry b c th c f S d R ll th t d d t pod soc h b tw th m (b) R f m t S-R C dt d t m t (S) k R t hgh b1ty th R d R (th p ts ory) bec se R li b f ll w d (w d d f d) by S_0 l d g t R_0 g l t m l s espo se

ts t gue g wh h of tw l ghts w ll e me n i the pe imenter u es r d m der but e li ht elat ely mo e f eq ent tha the r

them ti l model a e ot lim ted t th c ity t peet ti in fact by p ov di g tra i t qu t s th y m y e l that some of d t n t on betw n re f c me t a d ntu srt rp et t ns e c ent fic lly un mpo ta t r a ties of model h bee p ided by R B h d F M t ll r F R tle d oth ll f the wpoi t thu f m to d l fy s b t o a so at n th i and e ommo ly ped t geth s tim l s- e p s S-R th s Some S-R psy h l g t ha e dev ted m e ntion t e mple h ma l a g in r te t l m m zati n per ept l m t k ll see exp rime t re e l l wl l p pert at th n lev l of compl ty u h as er l po ti n rts, short-c itt g o pl ce k pp g te de s, int li t nd int l t effect Th wh ro eti al wr t ng in l de tatements d i g m th les l of c mpl ity e c mm nly known f t al t f wh m A L Irv A W M l n, a d B J U d rwood c nt mp ry ep e tat

Cognitive concept S t ppo t o to the S-R eori ts e a umbe f p ychol gi t wh em h ze th mp rt n f g t f t s n le rn g th t is pe ept l d ti l p o e tinct f m rim t h b ts Th y e le ig n t m ly ha of d t oned fle uti a a gn f ll w g p oce wh ch th l r e om h w k w wl at l d to wh t d c n nod fy h beh r d ngly Wh t i le rned n n ly l k f ll w ng m p th l k the lding f a m em t p tte n fi ed by h b t Al tho gh th p geon e p ■ n F g l re sed t ll t t f m nt theory th y ls p e t n ad pt t t the p tt ed at f th tim

l ti n in time the u of the cl k by the pigeon is here t with cog tive theory Cogniti e the ri t tend t u e ch concepts a ins gl t or ex pectat n when they de cribe the c ntrol of be ha i r The nam a ated with the c gniti e po t n i clude tl e Ce t lt p ychol gi t espe c ally W lfg ng K hl r and Kurt Lew and ome ne behs iori t f r i tance Edward C T lman and Karl S La hley

Wl le f a t me the inter t in l eha i ral law o had wed interest in neur phy iol gical co relate of learn ng ■ e 1950 there h been re newed nter t n br n pr c e underlying le rn ng Thu far the pe ifc eur l hanges related to l rni g a e u known *Se* P YCHOLOGY PHYSIO LOGICAL AND EXPERIMENTAL [E R H]

Bibl ogr phy E R Hilgard *The i of L* ■ *g* 2d ed 19 6 J A McGeoch nd A L Ir o *The Psych logy f H ma L rn g* 2d ed 19 2 R S W d rth and H Schl be g *Exp r m t l Psych logy* r ed 19 4

Least action principle of

L ke Hamilt n pri pl the pr nc ple of le t a t n s a ar at n l st tem t that f rm a ba i f om wh ch th eq at n of m ti n f a la cal dy m al ystem m y be dedu ed (s ■ HAMIL TON S PRI CIPLE) Co ider a mechani al ystem d c bed by c ordi te q q_j d th ir an ni lly j gate mome ta p_1 p_j (s e HAMILTO S EQUATIO S OF MOTION) The ct on S a o ated w th a egm nt of the traje tory of the y tem is defi ed by

$$S = \int \sum p \, dq_i \tag{1}$$

wh e the teg al i eval ated l ng the g en egme t of th tr j ct ry The a t o t of i t r t nly wh the t t l e gy E on rved The pri c ple of le t act o tat that th t j ctory f th sy tem i that path whi h m ke the al e of S tat on ry rel t t ea by p ths b tw n the me c nfig rati n d f wh ch the e gy h s the m c tant alu Th p ple i mi n m d as ly the t t ary ■ ope ty i equ red It i a m n mum p ciple f ffi e tly sh rt but fi ite egme t f the traject ry (■ MI IMAL PRI CIPLES)

Let

$$S + \Delta S = \int \sum (p + \delta p) \, d(q + \delta q) \tag{2}$$

wher $p_j + \delta p_j$ a o ally c jug te t $q_j + \delta q_j$ Negle ■ g e d rde terms

$$\begin{aligned} \Delta S &= \int \sum (p \, d\delta q + \delta p \, dq) \\ &= \int \sum (\delta p \, dq - \delta q \, dp) \end{aligned} \tag{3}$$

wh e n i tegr t n by part has b mad the i teg at d p ts n h g

The i h g f ΔS r q th nt gr d to b pe f t d ff i l of a q ant ty who d i t h Th coeffic e ts f th r at s

$\delta q_j\ \delta p_j$ need not vanish separately because the variations are not independent the varied qs and ps necessarily being canonically conjugate

$$\sum_i (\delta p_i\, dq_i - \delta q_i\, dp_i) = dU(q\,p) \qquad (4)$$

where
$$\delta p_i = \frac{\partial U}{\partial q_i} \qquad \delta q_i = -\frac{\partial U}{\partial p_i} \qquad (5)$$

Writing $U = -H\ \delta t$ leads to Hamilton s equations of motion

$$\dot p_i = -\frac{\partial H}{\partial q_i} \qquad \dot q = \frac{\partial H}{\partial p_i} \qquad (6)$$

The quantity $H(q\,p)$ known as the Hamiltonian function does not contain the time explicitly because $U(q\,p)$ cannot be a function of the time as the end times are not fixed and in general will vary as the path is varied Thus the principle is useful only for conservative systems where H is constant

If $H(q\,p)$ consists of a part H_2 quadratic in the momenta and a part H_0 independent of the momenta then

$$S = \int^{t_2} \sum_i p\,\dot q\ dt$$
$$= \int_t^{t_2} \sum_i p\ \frac{\partial H}{\partial p_i} dt$$
$$= 2\int_t^{t} H_2\, dt$$

by Euler s theorem on homogeneous functions Usually H_2 is the kinetic energy of the system so that the principle of least action may be written

$$\Delta \int_t^{t} 2T\, dt = \Delta \int_t^{t} 2(E - V)\, dt = 0$$

where V is the potential energy

The principle of least action derives much importance from the fact that it is the action which is quantized in the quantum form of the theory Planck s constant is the quantum of action *See* QUANTUM THEORY NONRELATIVISTIC [P M S]

Bibliography *See* LAGRANGE S EQUATIONS

Least squares method of

A method due originally to A M Legendre of obtaining the best values (the ones with least error) of unknown quantities suppo ed to satisfy a system of linear equations of the form

$$\begin{aligned} M_{11}a_1 + M_{12}a_2 + \quad &+ M_{1m}a_m = b_1 \\ M_{21}a_1 + M_{22}a_2 + \quad &+ M_{2m}a_m = b_2 \\ \\ M_{n1}a_1 + M_{n2}a_2 + \quad &+ M_{nm}a_m = b_n \end{aligned}$$

where $n > m$ Since there are more equations than unknowns the system is said to be overdetermined Furthermore the values obtained for the unknowns by solving a given selection m in number of the equation will differ from the values obtained by solving another selection of equations In the physical situation the b_i are measured quantities the M_{ij} are known (or assumed) quantities and the a are to be adjusted to their best values

Consider a simple example A quantity y of interest is supposed (perhaps for theoretical reasons) to be a linear function of an independent variable x For a series of selected values $x_1\ x_2$ of x one measures values $y_1\ y_2$ of y The expected relation is

$$\begin{aligned} x_1\alpha + \beta &= y_1 \\ x_2\alpha + \beta &= y_2 \\ x_3\alpha + \beta &= y_3 \end{aligned}$$

and the problem is to find the best values of α and β that is respectively the slope and intercept of the line which graphically repre ents the function The best values of α and β in the lea t squares sense are obtained by writing

$$\eta = y - (x\,\alpha + \beta)$$

and asserting that

$$\sum_{=1} \eta^2$$

shall be minimized with respect to α and β that i that

$$\frac{\partial}{\partial \alpha}\sum_{=1} \eta^2 = 0$$
$$\frac{\partial}{\partial \beta}\sum_{=1} \eta^2 = 0$$

This leads to the two equations

$$\alpha \sum_{=1} x + n\beta - \sum_{=1} y = 0$$
$$\alpha \sum_{=1} x^2 + \beta \sum_{=1} x - \sum_{=1} xy = 0$$

which may be solved for α and β For m rather than two unknowns the generalization is obvious in principle although the labor of solution may be great if m is large unless a high speed electronic computer is available

It should be noted that the measurements y in the example have all been assumed to be equally good If it is known that the measurements are of variable quality a weight may be attached to each value of y The least squares equations are readily modified to take this into account

$$\alpha \sum_{=1} u\,x + \beta \sum_{=1} u - \sum u\,y = 0$$
$$\alpha \sum u\,x^2 + \beta \sum u\,x - \sum u\,xy = 0$$

where u is the weight of measurement y_i

The least squares equations can be sh wn to lead to the most probable (in the tatistical en e) alues of the unknowns under a variety of a ump ns abo it the measurements and their weigl t In application in the physical scienc h we er it i rarely po ible to show th t one s l er ati n sati fy all or even any of the a sumption How ever the co dition may l a appr ximately ati fied

an in tan s, and the meth d w dely used se of its con e ience The empir c l ult at th k wn so d termined l ad t excelle t representati s of the data n the u ual e S e ERSE FITTI [M H H]

Bibliog phy A G W th ng and J Geffner *Tre nt of E p rim nt l Data* 1913

Leather and fur processing

Leather a d f s ha e be n e t nuo produc l r th n almo t ny othe mat ial yet are still n que m y p ope t es a d are m ng tl e most co pl x n hem try d te hn l gy Al h gh th m ha m of ts n ng s n t yet u de tood compl t ly h m c l a d phy cal ntr ls form ty of p od cts

Th h des nd ki f m which l ath s a e tan ed th the e pti n f the r pule l des (sn kes, l zard a d c ocod les) ar the p ri h bl by p od t of the me t indu t y Th e m t mo ly empl yed l ted i T bl l Le er b t still la ge, mbe s f hor eh des d kin of ep tiles, tri h a d e m l e ta ned a a il ble Furs e the pr m p od ts f t apper and breed ers at a e seq c p od ct depend la gely on dem nd

About 80% f all leath r prod ed ed f r shoes, d lee m unt f cl thing h db g l g g t a m belt g m h ical g od p ct f mes, b llf ld d keyca es F s e used f luxury garm ts In a n leathe s lso a lux ry m t l bec u if all th w ld p pu la e ld aff d hoe th l ther s ppl w uld be gros l i deq te

les l l th r a d f d p d p im r ly n th ir be tv a d feel d e d ly n h m c l d phy ic l p op rt es T bl 2 umm ze pr p erties f pri p l le the Th x lle t b to es t e fle i g l fe d m s n l tabil ty d po perme b lity u t ble

Spec l l th rs ch a h m s (lt n ed) posses high wat b pt n d buff l d aw hd posse gr t b r s t c

Bec se h des nd k l ble d ubje t to p t la t n p p m n f p es rvat n a e esse t l Aft ool g t m s a smal he t nd h g t m e blood th y p ked e f ll w th l n dry lt mm ed b a d then d ned Th y be sh pp d ll er th ll d h ld f l t 2 y a i thr d tion, nd l g unde refrig ti n S n o had dry g used a n lt rn t t alt in em te r s, but th le th r ly f t p qu l ty Be

Table 1 Animals used for le ther

	World pop l ion	A I k H	
		W H	U ted St tes
Ca le calf	813 000 000	1 0 000 000	0 000 000
W ter buff l	6 00 000	8 900 000	
heep la b	8 000 000	160 000 000	1 000 000
Goa kid	306 00 000	11 000 000	133 000

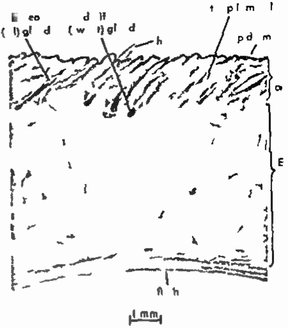


Fig 1 Th h r l gy of ttl h d

u wool is the nd ry prod ct of sheep t i remo ed in the p ck ng ho e r pullery l efo e k s ar h pp d

Structure of hides Fig e 1 illu trate the h s t l gy of attleh de Th dark a eas fr m p derm to base of h ir po ket is kn wn a g ai In t a angem nt f la ge or sm ll ha p cket s d mooth gh fa e th g in gi es a h l the it ch ra ter ti ppea n e

The l ght r deeper are ch ra te ized by th pr ou ced th ee d me o l m t e of fib r in fiber b dl s i the c i m mpo ed ma nly f the i ot n ll ge ll side p t hide a d kin c tai lip ds ca bohyd ates in rga s lt d wat S e INTEGU ENT

Processing The ta ne s sk ll co t f proc s g h des a d kin f ry g i th cknes nd text e t d e l thers f reas ably uni f rm q lity wh l p p tuati g r nha c ng th i ppea a ce lo g fle ing l fe ab a i n res tan e d p p m b l ty

Wet pe t o (be mh use) After hides nd k h e bee r wet th y m st mo p gres ly thr ugh the p ce ope tio s t a d l t p t l to Th y fi st o ked i l an l wate i r ct la p ts to d l r hyd te p t d lo n d rt E e flesh i m d mech lly aft ak

H des a e t placed p t nta n ng solu ti f lk l—hyd ated l m Ca(OH) w th w th t od m lfide N S Beca e of th loos g d l t f th lkal t the ha r root h n b m ed m cha ally aft r th s tr tme t F s nd heep k n wh h re t n d w th th ha e n t gi n th lk l tre t m t Aft ppl t n of od m sulfid p t th fl h h p k a e h g r nght d th wool p lled ff th t d y

Table 2 Leather properties and uses

Properties and uses	Cowhide Light (upper)	Cowhide Heavy (sole)	Calfskin	Sheepskin (lambskin)	Goatskin (kid kin)	Horsehide
Unit of sale	side (½ hide)	bends shoulders bellies heads	whole kin	whole skin	whole skin	butts fronts des
Area or weight	10–25 sq ft	30–60 lb per hide	3–[illegible]0 sq ft	3 10 sq ft	2–8 sq ft	3 7 sq ft per cut
Thickness 1 oz = 1/64 in 1 iron = 1/48 in	2–6 oz	5–12 iron	2–4 oz	1–4 oz	1 3 oz	3–6 oz
Main uses (indicated by x)						
Shoe uppers	x		x		x	x (Cordovan)
Shoe linings			x	x	x	
Shoe soles		x				
Garments	x		x	x		x
Gloves	x (work)			x	x	x (work)
Handbags	x		x	x		
Billfolds	x		x	x	x	
Luggage	x	x				
Transmission belting		x				
Mechanical	x	x				
Special characteristics						
Abrasion resistance	E	E	E	E	G	E (Cordovan)
Flex no life	E	E	E	G	E	E
Appearance	E		S	G	E	S (Cordovan)
Finish (polish)	E		S	G	E	S (Cordovan)
Comfort	E	E	E	E	E	G (Cordovan)
Drape	G		G	E	G	G
Protection	E	E	E	G	E	E
Dimensional stability	E	E	E	E	E	E
Vapor permeability	E	M	G	E	G	L (Cordovan)
Relative cost	M	M	H	L	H	H (Cordovan)
Tannages (indicated by x)						
Chrome	x		x	x	x	x
Vegetable	x	x	x	x		
Alum				x		
Formaldehyde				x		
Tensile strength 1 in width sample thickness as used	250 lb	700 lb	[illegible]00 lb	90 lb	1[illegible] lb	[illegible]0 lb
Bursting strength	300 lb		300 lb	60 lb	[illegible]50 lb	300 lb

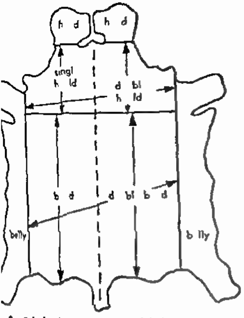
E excellent G good M medium L low S superior H high

Sole leather hides and many others are relimed after dehairing to prepare fibers for tanning Cattle hides for upper leather are split after liming (alternatively after chrome tanning) to reduce thickness to that acceptable to modern wearers The stock is next delimed that for chrome tanning in a bate of pancreatic enzyme activated with a solution of an ammonium salt which also selectively removes certain proteins Hides for heavy vegetable tanned leathers are immersed in solutions of weak organic acids such as lactic or hydroxyacetic for surface lime removal without loss of hide substance The stock now leaves the beam house for further treatment

Tanning Tanning is the changing of hides and skins into insoluble nonputrescible leather without destruction of the original structure Furs are partially tanned or dressed without loosening or damaging the filaments or fur

For chrome tanning the stock is saturated with a solution of a reduced chrome salt usually hydrated basic chromium sulfate $Cr(OH)SO_4$ in a revolving drum After the hide is saturated this unstable compound is precipitated by mild alkali such as sodium bicarbonate $NaHCO_3$ and combined chemically with the collagen In vegetable tanning the stock is given a series of baths of gradually increasing strengths of vegetable extract mainly imported wattle or quebracho This countercurrent method assures complete penetration of the fibers without distortion of the hide Vegetable extracts are adsorbed but do not form strong chemical bonds with collagen

In a process known as tawing alum is used as a partial tannage supplementing or replacing chrome Formaldehyde is sometimes used to produce white fluffy leathers Zirconium salts make pure white leather of great strength



 2 Sol l th ut f m tll h de

Dy g d l bricati n Upper l th s a e dyed
ith a d b ca tl e dyes n drums Clo e con
ol of pH t e t l to s e u form a d c
et h d Wh l in th dr m l br nt i the
rm of sulf ted n m l eg tabl or m eral oil
m l n are added The e are t ken up le
n ly by th l ather

H vy le th s e rely dyed but r gi n n
il lo d The fu t n f the l b i nt i both p
e nd h avy l athers t p ote t the fibe s d r
ing dryi g d a b q nt pr c sing and t l b i
ate the fin h d leath L b t e e ry
bec use the nat l il h e b e sapo fied nd
removed by lk l t atme t d g w t p
ng

De l pm t w k n 1945 n t n g a d
et p t t ac t e ath r th w te h s
h wn th t the t me eq ed f the p at
e be c t t min tes The method m exp ri
ment l pe ation

Dryi g B th h vy a d pp l th s e next
pa sed thr gh e ol i g cyl nd s w th r d l
blades t rem wat d sm th the gr n Most
uppe l ther n t pa ted n pl t gl r
en m lled ir n beet and d ed th t mp e
smooth es and u if rm ty C d i dry
room ar u ed t r mo e a t lled mo t of
m st e, w th exact g hed le f temp tu
and hum d ty co l to d ha d g r h
ng Upp l th s r q r ho rs d h vy l th
ers d ys, t dry

F nishi g Upp l th s part lly r hy
drated a d softened (t ked) by m h es wh h
wp t i d d l fibe w thout ptu g fib
b dles. Seve al ts f fi h g mat als a e
ext applied by ha d p ay g a t m t
co ey rs Pyr yl l qu p ly cryl t mul

s ns cryl trile or p gme t fin he f ca e n
shellac p gme t are employed as indicated but
they mu t not bsc e th grai [redacted] iled l seed il
is u d to c at p tent leatl e

Gl zing or p li h g m y b u ed in enh ce
l ter A good fi ish i l tro w ter repell nt
a d vap p rmeable The fle h side f upper
leath r i made att cti e by buff ng n m ch nes
w th cillat ng cyl der co e ed with fin sa d
pape S ed leathers re fini hed m larly n the
flesh side to p od ce a soft fi e p Nubuck i
the tradema ked name f r cowh de with a sueded
g ai surfac

Sole and h avy leathers are rolled under high
pre ur (after dampen g) to compact fiber for
m ximum wea then w xed

Furs Dres ed animal pelt u ed f r garments r
ad r me t a e k wn a f s Som times the fila
me ts ha r are k own as fur Rabb t fur s
u ive sally ed f felti g hats *Se* TEXTILE

O g ally f el th g wa w rn fo p otection
t day its style nd luxury f at es p edomin te
The pelt of m k be e f r eal leopard il er
and other f es ma te and e m e c me fr m
wild r an h n mals In addit on wool sk n
ku k r bb t nd m sk t re pr c ssed to im tate
arer m e co tly fur i dema d

F p lt r coll ted all o e the wo ld by
g n zat on s ch s the H d n Bay Comp ny nd
old at auct on in London Le pzig New Yo k
Le ingrad Mo tre l or St Lo s (Ala kan se l)
The fi t pelt m f om ld cl mates

F filam nt a ha bed fe gthwi but are
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filament ap rt and pre t m tt ng d are re
mo ed in pr essi g

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n l pelt a d th ca e ob erved n t p es rv t on
d termi e the fin l al of the produ t

Th p o e or or d es er rehyd tes the pelt by
so k g t in w t d em es dhe i g fl h w th
a kn fe mach e Furs e oft n tacked r t g
gled n t et hed p tu n bef re le theri g or
taw g Formald hyd c be used s eithe the
mpl te r th partial t n g also nat l l
d hyde f om the d e mp t on of ox d z ng l
re ed The d s ed p lt mu t be soft nd d apey

S b equ t oper t s are clo ely gu rded se-
ret B t dy i g s ft employ d to alte lo o
h d t m k th m ev n Im t t on furs are
s lly dy d t m l te th nat l c l ri g Dye
mu t ott t n fe t th pe n o loth ng of th
w r p ce lled rocki g

When nece s ry gu rd h t e r m ed by
pe al m hi e F s e p atedly tumbled n
l ed o s n ed d m t s fte th m pol
h th fil me t a d r m ex dye S wd t
r p l e d w l ut h lls re ft dded to s-
st in th pol h ng L te s h ced by l c
t ify ng m h e n wh ch rap dly rev l g cyl
d w th ltern t g qu d ant f cl th ng ard
nd h t o mb nd r th filaments

Skilled sorters select matching skins and from these the furrier pieces together the garment. Dropping machines cut and stitch the pieces so that no joint can be detected along the surface of the fur.

Mouton, closely resembling beaver, is made from sheepskins with the wool attached. Only 5% of the pelts available have fine enough wool and adequate fiber density for the purpose. Raw pelts are washed with detergent solution, tanned with alum, dyed, combed, clipped, and ironed repeatedly to straighten the filaments. Formaldehyde is used to set filaments and to enhance luster.

Persian lamb is made from the skins of unborn lambs from Afghanistan. It possesses fine filaments and tight curls. Rabbit, skunk, opossum, and muskrat are given appropriate variations of the treatment outlined above to produce the desired imitations, such as imitation ermine from rabbit. Labeling restrictions protect the customer from misrepresentation. [K.E.B.]

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Lecanicephaloidea

An order of tapeworms of the subclass Cestoda. All species are intestinal parasites of elasmobranch fishes. They are distinguished by having a peculiar scolex divided into two portions. The lower portion is collarlike and bears four small suckers; the upper portion may be discoid or tentacle-bearing and

Scolex of a lecanicephaloid tapeworm.

is provided with glandular structures (see illustration). The scolex is usually buried in the intestinal wall of the host and may produce local pathology. The anatomy of the segments is very similar to that of the Proteocephaloidea. Some authorities place the lecanicephaloids in the order Tetraphyllidea, to which they are obviously closely related. Essentially nothing is known of the life history of lecanicephaloids. *See* CESTODA; TETRAPHYLLIDEA. [C.P.R.]

Leech

Any one of about 290 species belonging to the class Hirudinea, phylum Annelida. Leeches are primarily fresh-water animals; however, some live in damp earth and some are marine. Most of them are parasitic on aquatic vertebrates, although some are predacious on worms, snails, and other invertebrates. Turtles are an especially common host. Some species attack the inside of the mouths of fishes and can cause their death. The large land leeches of southeastern Asia sometimes cause severe pain when they attack man.

The leech *Hirudo medicinalis*; length to 8 in. (*From J. G. Wood, Popular Natural History, Porter and Coates, 1885*)

The medicinal leech, *Hirudo medicinalis*, was formerly widely used in Europe for blood letting and may still be rented in a few places for the removal of blood from black eyes and other bruises. The horse leech, *Haemopis marmoratus*, a large predacious species living in the mud, is highly favored in parts of the Midwest for catfish bait.

In their basic anatomy leeches are similar to the earthworm. They lack setae. The coelom is greatly reduced by the invasion of mesenchymal cells between and around the internal organs. Leeches vary in length from ¼ in. to 1 ft. Most American species are less than 2 in. long. They are flattened and composed of 34 segments but appear to have many more segments because of grooves around each segment. They are usually greenish to black in color, but a few are brightly marked. They are provided with a sucker at each end.

Leeches are hermaphroditic. In some species a spermatophore containing sperm is attached to the back of the recipient, where it digests its way into the body cavity and fertilizes the eggs. In others copulation occurs, usually with reciprocal fertilization. Eggs are deposited in a cocoon and hatch into young resembling the adult. *See* EARTHWORM; HIRUDINEA. [J.D.B.]

Leg

The portion of the lower limb between thigh and foot. All limbed vertebrates show a similar structural pattern based on embryologic development but with differences in proportion and rotation. The leg bones are the tibia, a large weight-supporting shin bone, and the slender rodlike fibula. Compartmentalized muscle groups include functional sets which act on the foot, ankle, and thigh. Such mu-

l m v e the mo the po nt to wl ich tl ey ar a ked or immobilize t t nt mo em t as wh n standing (se MUSCULAR SY TE I) Blo d ves sel and n rv ar ppl ed by low r b nches f th (m r l n y and l e p n l nerv re pec ti ly two s t of e s the up ficial a d th deep drain th blood t th thigh S SKELETAL SYTEM [E G S T]

Legume

A dry dehiscent f u t d t ed from a ngle mple pist a d hi h wh n mature pl t along both d rsal a d ntral sut e nto two v l es See FRUIT (BOTA Y) The term is al u ed to d t a pl t f the order Ro ales th t bear this kind of fru t (se ROSALES) The l um or pea f mily Legumin s eh m teri t cally cont ns a singl w of seed att ched al g th l w r or mr l sutu e of the f t (pod) The e ds a e highly tr t u d e al f th l gum u pe ws f rm h a la ge am unt f food f both m n and be t S SEED (BOTANY) Nitr fying ba teri living symb t lly t the oot of leg m ac mul t nitr g u mat ri l h c the e pl nt a d t be go d f the l (ee NITROBAC TER CE E) Am ng th m r c mmon and imp r tant legumes lf lf b n l r owpea k dzu lespedeza loc t l p p a pe nt s y be s and tch

F r f rthe i f rm t n e sep rat rticle listed by th abo ommo names [P D S]

Legume forages

P ants of th l g me f m ly ed f r grazing h y or sil g Ab ut 25 sp s ar c lt ated th United t tes and a la g r numb r u ed fo graz g n range a d n mp ed p t es Th e t ted k nds were br ught to th Un ted Stat s from th p rt f th w rld Plant x plorations a be ng c tin d t th r upe i leg n pe es or ri t The spe es n g a d m ro ed p t e e n t and n tural ed pl ts n t so n by man

The pri pal lt ted legume f rages re h t ed im n and al ke cl e alfalf lesped za nd tches Swe tcl e field pe ro gh w ter pe o pe t f ls bu nd b t to lo r k dzu h t y nd lv t b a b d foot t ef l a d ev r l oth l gum a locally import t

Legum f ges a s ch n p t d in th m al ent al f n m l tr t They used t uppl ment g ss fo ag whi h re h in b hyd tes U ually a mpatible m xtu e f grasses nd l g me w ll p d ce la ge y ld th n eith al e

Som l gume h ere to t t g zing am mals th t som t mes au bl at B ty c d fermen a f d g s soc t d w th th l gume fo ge Con d rable e r m t be ex e cised th feed g and t ge f th e pl nt S ALFALF CLO ER COWPEA KUDZU LESPE DEZA LUPINE s e also COVER CROPS LEGUME POI O OLS PLANT [P T]

Bibliography G ass USDA Yea book Agr 1948 H D H ges et l (ed) *Fo ag s* 1951 C V Piper *Forage Pl t and Th r Cultu* re ed 1924

Leishmaniasis

An i fectious d ea cau ed l y flag llate pr m o- a species f the genu *L ishma ia* Th dise e is tr n m tted to m n by the b ting fly *Phl b t m s* a d d t ib t d widely in tr pical and ult opi al ar a V ceral utaneou and m ocut neo s lei hmania s are th th r e human variet u ually d ting hed The th ee rre p d ng pe f th flag llat described fr m m n e alm t in di t gui hable e ept for the sympt m m pl xes they ca e Ant mo y a d amidi m po ds e ed f r t e tment and the bit ng fly c trolled h efly by the of in ctic des

Vi c al lei l ma a or kala zar i cha cte ized by p ol nged fever nlarged pleen anemia d rea e i the numbe of wh te ll change in pla ma p ot n nd oft n by p gm tat n of the ki Cult es f blood or ti ue c ll t ined p ep at n f t s a e ed t dem trate *L d n* th cau at e rg i m

Cutane u lei hm nia s s att ib ited t the spe e *L t p a* Les s in man are limited to the ki and beuta eou t Th h man di ease i benign en wh n unt eated it nt nu s th gh ut a per od of month It s sponta eo ly elf lim ted d ration lea es a indel ble scar and i ften f ll wed by mmu ty to e nd at in k very in ual n p oto n d es

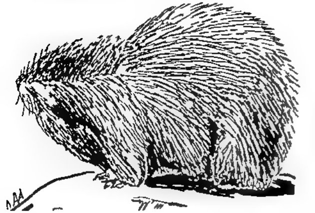
M oc ta eous le hm ni s tta ks the l ing of th m uth a d a l pa ages s well a the kin and ub utan us t sue Lo s of p t s of the mo th ph rynx or n trils occ further m til t m y r ult f om the f rm ti f rt fi ial c mmu at n b tw e th n e and m th *L b a l n s* fo d n the l s n and its immedi t ty S e DIPTERA TRYPA OSO IATIDAE [D W]

Leitneriales

An d r f the pl t bcla s D otyl d n ae c n ta n ng one f mily (*Leit ria e*) w th one g nu (*L in a*) d p c e (*L flo ida a*) The plants re h ub m ll tr es g ow ng n sw mp of the uthe n U ted St t The me c rkwood i ed be a se they p d ce the l ghtest w od (pec fi g a ty 0 21) g wn in th Un ted States S DICOTYLEDONE E BRYOPHYTA PLANT KINGDOM [P D S]

Lemming

Any f eve al ath mall hort ta led mall d ode t fo nd n Eu a a d N rth Am i a Th e th d t t gen ra f im la nim l lled l mmi all th ubfamily M rotina fam ly C t da The br wn lemm ng ge u

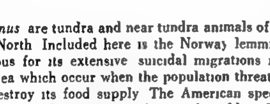


The collared lemming Dicrost yx rubricatus length to 6 n (From E L Palmer Fieldbook of Natural H s tory McG aw Hill 1949)

Lemnus are tundra and near tundra animals of the far North Included here is the Norway lemming famous for its extensive suicidal migrations into the ea which occur when the population threatens to destroy its food supply The American species has dispersal migrations of a much milder char acter The collared lemmings genus *Dicrostonyx* are the only small rodents that turn white in the winter They are strictly tundra animals The bog lemmings of the genus *Synaptomys* occur over most of the northern and eastern United States and much of Canada *See* Mouse Rodentia [J D B]

Lemniscate (of Bernoulli)

A curve shaped like the figure eight referred to by James Bernoulli in 1694 Let F_1 F_2 be points of a plane π with $F_1F_2 = 2a$ $a > 0$ The locus of a point P of π which moves so that PF_1 $PF_2 = b$ where b is a positive constant is called an oval of



A lemniscate

Cassini The lemniscate is obtained when $b = a$ Its equation in rectangular coordinates is $(x^2 + y\ )^2 = a^2(x^2 - y\ )$ and in polar coordinates $\rho\ = a$ cos 2θ It is the locus of the point of intersection of a variable tangent to a rectangular hyperbola with the line through the center perpendicular to the tangent The area enclosed by the lemniscate $\rho^2 = a$ cos 2θ is a^2 *See* Analytic geometry [L M BL]

Lemon

The fruit *Citrus limon* commercially the most im portant of the acid citrus fruits Its origin i some what ob cure but evidence points to southern China and upper Burma as its nati e home There are many varieties with wide diver ity in tree vigor size shape and character of fruit Many of the e diverse lemon types are no doubt hybrids with othe citrus The rough lemon is probably such a hybri and while scarcely edible it is quite importar because it is frequently used as a rootstock o which other citrus is budded (*see* Budding)

The true lemons are small evergreen trees th leaves of which have petioles with very narro wings and give off a lemon odor when cru hed Th fruits are medium sized and elongated with 9-1 segments and few seeds *See* Fruit (botany)

The lemon C trus l mon (From L H Ba ley ed Th Standard Cy loped a of Hort c lt re ol 2 M cm lla 1937)

In 1955–1956 the United States produced 31 1 of the world supply of lemons California by fa the leading lemon producing state had 59 50 acres in 1957 Arizona second in lemon acreage rapidly increasing its acreage The average yearl value of the lemon crop in the United States at th packing house from 1948 to 1958 was $40 810 80

No other citrus fruit has such a wide variety uses Lemon juice very high in vitamin C is u e in beverages and to garnish meats and fish It ha many culinary uses especially in pies cakes ice candies jellies and marmalades Citric aci pectin and lemon oil are by products of the frui *See* Citric acid Fat and oil edible Pectin *see also* Fruit (tree) [F E C

Length

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Lens optical

A curved piece of gro d a d p l hed r molded te l, u ually gla s ed f r the ef act n of ht. Its two s f ces h e the s me s Usually s is an f r tat o symm try f r b th su es h ere o e r both f the surfaces can b c, cylindrical, or a general s rfac w th d ble mmetry Th i te ection po nt of the ymmetry s with the two s fa es called the front d k ertı es a d their sep at n ıs alled th kness f the lens

Compound lenses A mpound l s a com b f tw r m e len es ı which the c nd rf ce f o e len has the s me ad s as the fir t rf ce of the f ll wı g lens a d the tw lenses ar mented t gether Comp und l ses ar ed ın ead of ngl le ses for lor c rrection to trod ce a s rf ce whi h has n effe t n the aper re ray b t la ge ffects o the p ı cıp l r y or ce erva. Somet mes th t rm mp d len ıs pplied t a y ptı l y tem c tıng f mor an ne element, ev n whe they e n t ın c t ct gro p of lenses sed togethe a l s sy t m A mmetrı l le s a len y t m c stı g of o p rts, e ch f wh ch ıs the m rr ım ge of th the If p rt a m rror mage of the oth agnified m times the yst m s called hemısym etric. When $m = 1$ the y tem s d t be los mm t ıc

Single lenses Th l d m t r ofte called h h a pert r nd the at o of th ap rture o th focal l gth ı lled the rel t e apertu Thus l rt qu nt ty ıs m r ofte pec fied by ıts e proc l called th f mber Thu ıf the focal length ıs 50 mm and th l ne r ap rtu e 25 mm the rel t pert e ıs 0.5 and the f n mb r ı $f/2$ S FOCAL LENGTH

I pe l l t m f rm la th lens th ck es es (but n t the epar t o s of the le e) a e f quently neglected Thı le d t the on em t fection f th le

If ρ_1 d ρ_2 te th f ont a d ba k c rv t es f a len f f actı e de m d th ck es t t po

$$\phi \quad (\ -1)(\rho_1-\rho_2)+\frac{t(\ -1)^2}{\ }\rho_1\rho_2$$

The curv t r f th u f the ecıp oc l f ts dı s.

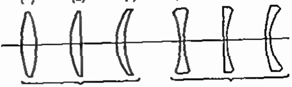
The d tan e f m the b k rt t th b k nod l po nt d t the b k foc l p t espe t ly are

$$S\ \phi = -(t/\ )(\ -1)\rho$$
$$S_F\phi = 1+S\ \phi$$

Th l t d t ften lled the b ck f c especially ph ı ph c pt

Th bend ng f a le ı h g th rv tur f th tw rf ces b th ame m t It doesn t hang th po f a thı le wh h $(n-1)(\rho_1-\rho_2)$ B nd g ı a mp rt t tool

( ) (b) ( ) (d) ( ) (f)



g g o po t d g g g t

l le

Fg 1 C mm typ f l ( ) B (b) Pl o (c) P t m (d) B c ( ) Pl c (f) N g t m l (F m F A J k a d H E Wh t F d m t l of Opt 3d d McG aw H ll 1957)

f th des g er f r ıt perm ts the replac g of one lens by an ther wıth ut hang ng the data of Ga ssian optıc

When thick l nse are ınvol ed Gaussian optıc remaın co ta t only ıf b th the powers f the th k l se nd th d sta ce between the b ck nod l p t of th fir t lens and th fr nt nodal p t f th nd rem ın nchanged Thus a bend ng f a thick len h ld be accompan ed by such a dj tment

The ptıc l center f a thick le s ı th ımage f the nod l p nt p od c d ı d the le All fi ıte ay thr ugh the pt c l ce t m ge parallel t the re pe t ed re tıo at the r e tr nc

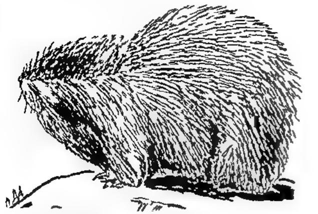
A opt cal cente ı t al ı a hemı ymmetr c sy tem It th p nt f ymmetry wh ch d ıdes the separ tı n of th two parts the rat $1/m$ If neg tı e al es f m r pe m tted y ı gle le s ıs hem ymm tr sy t m a d the poı t dı d ng th th ck e s f the l ns (the s p rat o f the two ert ce) ı a r tı eq al t th r tı f th two d ıs the ptı l ent f the l n

A le ı a d t be c lle tı g lens ıf $\phi > 0$ and a d e g g l s f $\phi < 0$ Wh n $\phi = 0$ the le s ıs af cal S e l typ f ollect ng nd dı e g ng l e a sh wn n Fig 1

The ıa e f mo t l n s re ıthe phe ıcal pl n b t pher cal urf e a used n o c on to mp the orre tı n w th ut chang g the power f the l ns S SPHERICAL A D ASPHERIC SURFACES OPTICAL.

A n t ıc le s a le wh two s rfac s ha the m nt If the bje t to be maged ı l at the nt ax s p nt ı h rply ım ged p n ıt elf nd s e the e ndıtı s ful fill d the mage ı f ee f om ymmetry Su h a le b s d s n dd t n l system t orre t me d n err s.

A othe typ of le co st of pla at c f ce followed by n ntr c s fac r vı e S ch a le d ıd the f c l le gth of the g n l l n t wh h t ı ıt ched by n th s n g th f mbe by a f to f w th t de t g th ı l c rre t n f the p e ed ng y t m It d s t od c urv t e of fi ld whı h mak eb l n g f th whol y t m d ı abl S ABERRATION OPTICAL

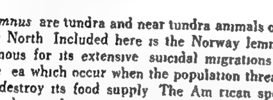


The collared lemming *Dicrostonyx rubricatus* length to 6 in (From E L Palmer Fieldbook of Natural History McGraw Hill 1949)

Lemnus are tundra and near tundra animals of the far North Included here is the Norway lemming, famous for its extensive suicidal migrations into the sea which occur when the population threatens to destroy its food supply The American species has dispersal migrations of a much milder character The collared lemmings genus *Dicrostonyx* are the only small rodents that turn white in the winter They are strictly tundra animals The bog lemmings of the genus *Synaptomys* occur over most of the northern and eastern United States and much of Canada *See* MOUSE RODENTIA [J D B]

Lemniscate (of Bernoulli)

A curve shaped like the figure eight referred to by *James Bernoulli in 1694 Let* F_1 F_2 *be* points of a plane π with $F_1F_2 = 2a$ $a > 0$ The locus of a point P of π which moves so that PF_1 $PF_2 = b^2$ where b is a positive constant is called an oval of



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[L M BL]

Lemon

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The true lemons are small evergreen trees the leaves of which have petioles with very narrow wings and give off a lemon odor when crushed The fruits are medium sized and elongated with 9-10 segments and few seeds *See* FRUIT (BOTANY)

The lemon *Citrus limon* (From L H Bailey ed The Standard Cyclopedia of Horticulture vol 2 Macmillan 1937)

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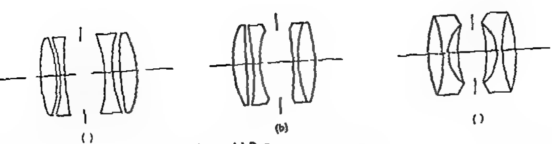
Length

Extension in space Length is one of the three fundamental physical quantities (the other two being mass and time) and therefore cannot be defined in terms of simpler quantities It is defined in terms of the operations involved in its measurement in reference to an arbitrary standard called the international meter Calibrated sticks or tapes are constructed by direct or indirect comparison with the prototype meter which is preserved at Sevres France various multiples and submultiples of the meter are indicated by calibration marks Lengths of objects or distances between points are made by direct comparison with calibrated sticks and tapes Decimal multiples and submultiples of the meter are frequently used in specifying length in English speaking countries the foot (0 3048 m) is a length unit *See* METER (UNIT) [D W I]



Fg 3 Type of t gm ts ( ) C l (b) T ( ) Dog

d fint n t f 16 o er tot l fi ld of 50 (F g a) Th len be a c me ted do blet f r co ect g hro t rr (F 2b) F practi l r a rev rsed me u w th th t p t ward the film fi used

Comb ni g t o m n c le es t f m m metrical l s th entr l top m kes t p ibl t correct s t gmat nd d to t o err for m ll apertu nd l g field angles (Fi 2c) Th ba type of wide- gle bjecti e i the Hy pe g n n ting of tw me i us l n c n centric w th the t p (Fig 2d) Th type f sy tem a be c rr ct d f r tigmat m nd fi ld c rv t re tot l field ngle of 180 but t n nly be used f a mall ap rt e (f/1?) e it cann t be corrected f pert re ror The ap rt e n be e sed to f/4 at the e pe e f fi ld a gle by th k g nd chr mati ing the me u le e ad a d ng ymm tri al eleme ts i th c nte th o t d of the b i leme

T p a hr mat c me ymmetri lly r gnd u d th t p led t th apl nat type f (Fig 2) Th typ w pher call nd umm t c lly c r ected S e the field ould n t rr ted c mp m e w a b d by b l ng t sag ttal and m r d nal fi ld curvatu n that e m urfac l e in fr t d the oth ab k f th film

Anastigm t c l ns Th d sc ry of the Petzval cond tio f r fi ld rrect n led to the o t t n l gm t l e f wh h tigm ti m a d curvatu e f f ld a co t d S h l ses m t co ta neg ti c mp ts

Th Cel (G) type co of tw a spaced he m t d blet ne ea h d f the stop (F g 3a) The Cook t ipl t c mbin s n g tr l n t th apert r t p w th tw p s t lenses, n f t a d the ther i b k It i lled a Tes a (F g 3b) if th la t po t l e cem ted d blet a Hel r f b th p rt lenses a e m t d Th D g r typ n t f tw len tem th t a n ly symm tr c l w th re p ct t the top each syst m nta ning thr e or more len es (Fig. 3c)

Mode n l ns T rea e the pertur the fi ld o b th it i freq ently ad ant geous t pla e le s by tw eparated l n e nce the me p wer i a h e d with l rg r r di and th mean that the i gle le e are u ed at m lle relati aperture The eplaci g f ingle le s by a m nt d l hang the c lor bala ce and thus the designer may ach mo e fa orable co dit on M eo the troductio f new types of glas (fi st th gl co ta n g bar m l ter the gla es c ta i g ra e earths) led to len le- ment wh ch f the same power ha e weake s r fa es and are th refore f g t help t the le s de igne

Of m d rn des gns the mo t ce ful are the so nar a modified t ipl t, e f rm of whi h i h wn n F g 4a th Bi tar (Fig 4b) a mod fied G u s bje ti e with a la ge p t e and a field of abo t 24 and th T pogo (F g 4c) a pe copic le w th pplem nt ry th ck m n ci to perm t the rrect n f pe tur aber at n for a moder at p rt e nd a l ge field One r two plane- pa all l pl tes s m times add d t orrect d st ti n

Sp ci l bj ti es It i f q tly de r ble to h ng the f cal l n th of an bje ti e Th is omet me do by mb i g a fixed near c m p e t beh nd th top w th an ex h ngeable et of omp n nt i fr t of th stop The d igner h s t b th t th rrors of th two p rts r b l nced o t eg dle of wh ch f o t c mp nt

Th t leph t bj et a p lly constructed obje ti e w th th re r d l p i t m fro t f the le t omb ne l ng f c l le gth with sh rt ba k f s S TELEPHOTO LE S

The P tzv l bject e ne of the olde t de igns (1840) but one of th m t ingen u It n i t n ge e l f f u l n es o d ed i tw p i wid ly ep ted f m ach th r Th fi t pai

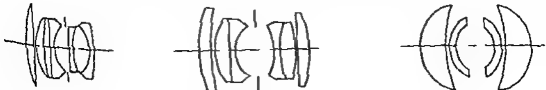


Fig 4. Mod ph tog ph l ( ) S o (b) B i ( ) T p g

Cemented lenses Consider a compound lens made of two or more simple thin lenses cemented together Let the power of the kth simple lens be ϕ and its Abbe value ν (*see* CHROMATIC ABERRATION) The difference between the powers of the *combination for wavelengths corresponding to C* and *F* is

$$\Phi_F - \Phi_C = \Phi/N = \Sigma\phi/\nu$$

where N may be considered to be the effective ν value of the combination The ν values of optical glasses vary between 25 and 70 with the ν value *of fluorite being slightly* larger (ν = 95 1) By using compound lenses effective values of N can be obtained outside this range Color correction is achieved as N becomes infinite so that $\Phi_F - \Phi_C = 0$ A lens so corrected is called an achromat In optical design it is sometimes desirable to have negative values of N to balance the positive values of the *rest of the system containing collecting lenses* Such a lens is said to be hyperchromatic A cemented lens corrected for more than two colors is said to be apochromatic A lens corrected for all colors of a sizable wavelength range is called a superchromatic lens *See* OPTICAL MATERIALS

LENS SYSTEMS

Optical systems may be divided into four classes telescopes oculars (eyepieces) photographic objectives and enlarging lenses *See* EYEPIECE MICROSCOPE OPTICAL

Telescope systems A lens system consisting of two positive systems combined so that the back focal point of the first (the objective) coincides with the front focal point of the second (the ocular) is called a telescope Parallel entering rays leave the system as parallel rays The magnification is equal to the ratio of the focal length of the first system to that of the second

If the second lens has a positive power the telescope is called a terrestrial or Keplerian telescope and the separation of the two parts is equal to the sum of the focal lengths

If the second lens is negative the system is called a Galilean telescope and the separation of the two parts is the difference of the absolute focal lengths The Galilean telescope has the advantage of shortness (a shorter system enables a larger field to be corrected) *but the Keplerian telescope has a real* intermediate image which can be used for introducing a reticle or a scale into the intermediate plane

Both objective and ocular systems are in general corrected for certain specific aberrations while the other aberrations are balanced between the two systems *See* TELESCOPE TELESCOPE ASTRONOMICAL

Photographic objectives A photographic objective images a distant object onto a photographic plate or film *See* PHOTOGRAPHY

The amount of light reaching the light sensitive layer depends on the aperture of the optical system which is equivalent to the ratio of the lens diameter to the focal length Its reciprocal is called the *f number The smaller the f number the more light* strikes the film In a well corrected lens (corrected for aperture and asymmetry error) the *f* number cannot be smaller than 0 5

The larger the aperture (the smaller the *f* number) the less is the scene luminance required to expose the film adequately Therefore if pictures *of objects in dim light are desired* the *f* number must be small On the other hand for a lens of given focal length the depth of field is proportional to the aperture

Since the exposure time is the same for the center as for the edge of the field it is desirable for as much light to get to the edge as to the center that is the photographic lens should have little vignetting

The camera lens can be considered as an eye looking at an object (or its image) with the diaphragm corresponding to the eye pupil The Gaussian image of the diaphragm in the object (image) space is called the entrance (exit) pupil The angle under which the object (image) is seen from the entrance (exit) pupil is called the object (image) field angle For most photographic lenses the entrance and exit pupils are close to the respective nodal points for such lenses the object and the image field angles are equal

In general photographic objectives with large fields have small apertures those with large apertures have small fields *The construction of the* two types of systems is quite different One can say in general that the larger the aperture the more complex the lens system must be

There exist cameras (so called pinhole cameras) that do not contain lenses The image is then produced by optical projection The aperture in this case should be limited to *f*/22

Other types of lenses A single meniscus lens with its concave side towards the object and with its stop in front at its optical center gives good

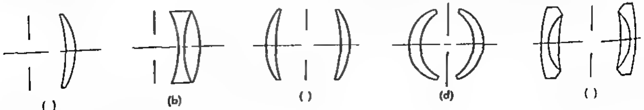
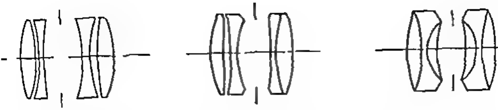


Fig 2 Older photographic lenses (a) Meniscus (b) Simple achromat (c) Periskop (d) Hypergon wide angle (e) Symmetrical achromat



( ) (b) ( )

Type F st gm ( ) C l (b) T ( ) D g

t f/16 er t tal fi ld of 50 (F g 2a) m be a c m ted d blet f corr ct ng u err (F 2b) F p ctı l ea n ed me cus w th the top t wa ds th film n sed

mb g t me ıs s l n s to f rm a ym c l l with nt l st p m kes ıt p ble orrect tıgmatı a d d st t n er or for l pert es a d large fi ld angl (F g 2c) b ct pe of de a l bje tı m the Hy n c n t t g of t m nı cu le e n th the t p (F g ?d) Thı type of ystem be rrected f a t ?m t m nd fi ld c rva e a total field ngl of 180 but ıt n ly ed f mall pertu e (f/12) ce t c not rrect d f pe t e r o The ap rt n sed to f/4 at th exp n e f fi ld ngle by g and ch matızı g the m n cu le e dd g symm t al elem t ın the ce ter or t de of the b c l m nts

po ıtı h mat me ı ymmetr cally nged d th t p led t th pl t typ of (F 2) Th type wa ph cally nd m t ally ected S c th field ld ot rrected a mpr m was chı ed by bal g t sagıttal d me ıd n l fi ld c rvatur h to e m g su f ce l e l t nd the ther b k f th film

f ast gmat l ns The d o ry of the Petzval d t n f r fi ld r t n led t the on t u t n ast gm t l ses f wh ch tıgmat sm d n t e f fi ld a c t d S th l ns m st n gat mpo e ts

Th Cel (Ga) type on t f two ır d a b m tıc d ubl t ne a h de of the op (F g 3a) Th Cooke t plet mbı es a n ga l n t th p rtur t p wıth two p tı es o e ın f nt d the oth r ı ba k It ed Te (Fig 3b) ıf the last po t l n a cemented d ubl t a H l a f b th p s t me t d Th D go typ c ı t f len y t m th t a ne ly symm t l w th re pect t th top ach y tem conta nıng three or m re le e (Fıg 3c)

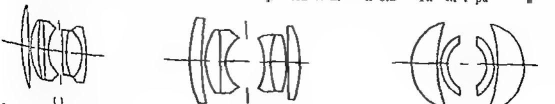
M der l n s T ı c ea the aperture the field r b th ıt ı f eq ntly d antag ıs t re pla n len by tw p rated l n e ın the me we ıs achı ed with l rger rad and th mean that the ıngle le e re ed t mall r rel tı ape t e The r pla g of a gle lens by a cem nted len cha ge the olor l al nce and thu the d ı er may chıeve m e fa o l l co d t n M e er the ı t od tı n of new types of gl s (fi st the gl e c ta ıng bar m lat th gla s c nt nı g r e e rth) led t l n ele m nt wh h f r the m p w r h e weaker ur fa es a d e ther fore of gre t h lp to the l n desıg er

Of m de n des ns the m t s cc f l are th So na a mod fied tr plet on f m of wh h ıs sh wn ın Fıg 4a th B tar (F g 4b) m dıfied Ga s bje tı with large pert re nd a field f about 24 a d the T pog (F g 4c) p ıs opı len w th upplement ry th k me ı cı t permıt th ctıo of ap rture b r at ns for a moder te pe tu e d a l g fi ld O e tw pla par ll l plat s e somet m dded t c rr ct d st tı

Sp cı l bj n s It ı fr qu tly desırabl t ch n the f c l length f n obje tı e Th ı som tım d ne by mb a fixed n r m p n ıt behind the top w th an x h ble et f omp ent f o t f th top The de g er ha t b e th t th or of th tw part ar bal ed ut eg rdless f wh h f ont mp e t n e

Th teleph t obje t ı a pe ally c tr cted obje t w th th nod l p t ı f ont of the l ns to c mb e a l g f c l l gth with a short b k f s S TELEPHOTO LE S

The Petzval bj tı e of th ld t de gn (1840) but o e f the m t n en It ı t ı g n al f fo le rde ed ı tw p w dely ted fr m h oth Th fir t pa



( ) (b) ( )

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where N may be considered to be the effective ν value of the combination. The ν values of optical glasses vary between 25 and 70, with the ν value of fluorite being slightly larger ($\nu = 95.1$). By using compound lenses, effective values of N can be obtained outside this range. Color correction is achieved as N becomes infinite so that $\Phi_F - \Phi_C = 0$. A lens so corrected is called an achromat. In optical design it is sometimes desirable to have negative values of N to balance the positive values of the rest of the system containing collecting lenses. Such a lens is said to be hyperchromatic. A cemented lens corrected for more than two colors is said to be apochromatic. A lens corrected for all colors of a sizable wavelength range is called a superchromatic lens. *See* OPTICAL MATERIALS.

LENS SYSTEMS

Optical systems may be divided into four classes: telescopes, oculars (eyepieces), photographic objectives, and enlarging lenses. *See* EYEPIECE; MICROSCOPE, OPTICAL.

Telescope systems A lens system consisting of two positive systems combined so that the back focal point of the first (the objective) coincides with the front focal point of the second (the ocular) is called a telescope. Parallel entering rays leave the system as parallel rays. The magnification is equal to the ratio of the focal length of the first system to that of the second.

If the second lens has a positive power, the telescope is called a terrestrial or Keplerian telescope, and the separation of the two parts is equal to the sum of the focal lengths.

If the second lens is negative, the system is called a Galilean telescope, and the separation of the two parts is the difference of the absolute focal lengths. The Galilean telescope has the advantage of shortness (a shorter system enables a larger field to be corrected), but the Keplerian telescope has a real intermediate image which can be used for introducing a reticle or a scale into the intermediate plane.

Both objective and ocular systems are in general corrected for certain specific aberration, while the other aberrations are balanced between the two systems. *See* TELESCOPE; TELESCOPE, ASTRONOMICAL.

Photographic objectives A photographic objective images a distant object onto a photographic plate or film. *See* PHOTOGRAPHY.

The amount of light reaching the light-sensitive layer depends on the aperture of the optical system, which is equivalent to the ratio of the lens diameter to the focal length. Its reciprocal is called the *f* number. The smaller the *f* number, the more light strikes the film. In a well-corrected lens (corrected for aperture and asymmetry errors), the *f* number cannot be smaller than 0.5.

The larger the aperture (the smaller the *f* number), the less is the scene luminance required to expose the film adequately. Therefore, if pictures of objects in dim light are desired, the *f* number must be small. On the other hand, for a lens of given focal length, the depth of field is proportional to the aperture.

Since the exposure time is the same for the center as for the edge of the field, it is desirable for as much light to get to the edge as to the center, that is, the photographic lens should have little vignetting.

The camera lens can be considered as an eye looking at an object (or its image), with the diaphragm corresponding to the eye pupil. The Gaussian image of the diaphragm in the object (image) space is called the entrance (exit) pupil. The angle under which the object (image) is seen from the entrance (exit) pupil is called the object (image) field angle. For most photographic lenses, the entrance and exit pupils are close to the respective nodal points; for such lenses the object and the image field angles are equal.

In general, photographic objectives with large fields have small apertures; those with large apertures have small fields. The construction of the two types of systems is quite different. One can say in general that the larger the aperture, the more complex the lens system must be.

There exist cameras (so-called pinhole cameras) that do not contain lenses. The image is then produced by optical projection. The aperture in this case should be limited to *f*/22.

Other types of lenses A single meniscus lens with its concave side toward the object and with its stop in front at its optical center gives good

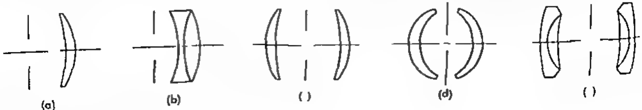


Fig. 2. Older photographic lenses. (a) Meniscus. (b) Simple achromat. (c) Periskop. (d) Hypergon wide-angle. (e) Symmetrical achromat.

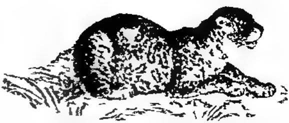
Leo

The Lion, m a t on my is a mag ifi ie t z d acal constellati n appear g d r ng pr ng and early summer It is th fifth ign of the Z d ac Leo i l d fi ed a d bears a cl e re emblance to th cr ture it rep esent. The head s th ed by gro p of t m called th S ckle Th fi st magni tud tar Regul s (little R ler) forms the handle f the kl Th ee sta to the ea t forming a m ll tria gl e n t t te th Li n s h unches with t b ght star D ebol (t l of the li) m g b l tar A ciated with thi con tella tion are the fam Leo ds h w of met ors h h an be seen r d at ng f om Leo in No emb l ch ear and appear g m pecially br ll ant at in rval f bout 33 ye S e CONSTELLATION METEOR. [C S Y]

Leopard

A la ge or *F lis pa dus* of the f m ly F lid f u d ver most f Af a e tern E rop a d cross A from the Black Se nt S be Th leop d a killed l mb and fa o fo ested rea lte liml g a t ee t aml h t p y Th e are al d ff ent ub p es z el d g th bl k l p d r pa th of outh n Ma la

Leopard a e mewhat smaller th l m tigers, and h e noti e bly l g r tail Th y attai a total length f 7 ft 3 ft of which is tail Hunt e c n ider them more dang rou than any other c t They re noct rnal p ying prim rily upon antel pe b bo n wild p and sim lar an mal They al o e t all dom tic im l b t rarely will attack and kill hum n The m t comm n f rm in stern Af ica and djace t A a m reddish brown and ma ked with pen to ettes or da k pot in a egul r p ttern *See* CARNIVORA LION TIGER [J D B]



Th l p d F l p d l gth t 57 (F om P M D c ed C ff N t l H st y C 1883)

Lepadomorpha

A suborde f th Th acica These barnacles h ve peduncl and a cap tulum wh ch i u u lly protected by cal areo plates Ca dal furc a d filament ry p e dage oft n are p nt The e u tace n a e ith r hermaph d tic or th e es may b sep rate

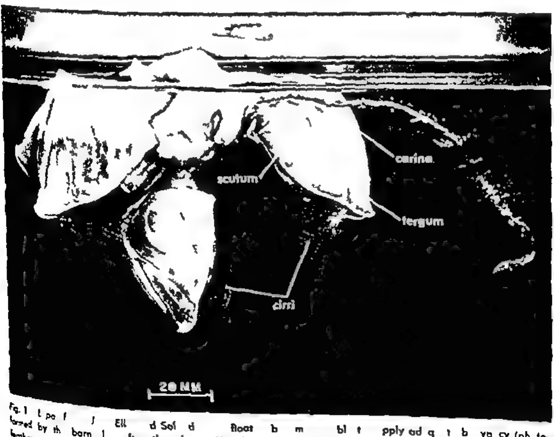


Fig. 1 L pa f J Ell d Sol d float b m bl t pply od q t b yo cy (photographed by th born l ft th bi ct (V f ll g ph by D P W l) together d th l k) wh h th cyp d ttl d

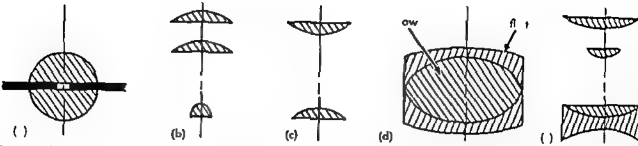


Fig 5 Some typical magnifiers (a) Sphere with equatorial diaphragm (b c) Planoconvex lens combinations (d) Steinheil triple aplanat (e) Chevalier type with long working distance

mented and the second usually has a small air space For a relatively large aperture it is excellently corrected for aperture and asymmetry errors as well as for chromatic errors and distortion It is frequently used as a portrait lens and as a projection lens because of its sharp central definition Astigmatism can be balanced but not corrected

For a discussion of lenses with variable magnification *see* ZOOM LENS *See also* GHOST IMAGE OPTICAL

Enlarger lenses and magnifiers The basic type of enlarger lens is a holosymmetric system consisting of two systems of which one is symmetrical with the first system except that all the data are multiplied by the enlarging factor m When the object is in the focus of the first system the combination is free from all lateral errors even before correction A magnifier in optics is a lens that enables an object to be viewed so that it appears larger than its natural size

The magnifying power is usually given as equal to one quarter of the power of the lens expressed in diopters *See* DIOPTER MAGNIFICATION

Magnifying lenses of low power are called reading glasses A simple planoconvex lens in which the principal rays are corrected for astigmatism for a position of the eye at a distance of 1 in is well suited for this purpose although low power magnifiers are often made commercially with biconvex lenses A system called a verant consists of two lenses corrected for color astigmatism and distortion It is designed for stereoscopic vision at low magnification

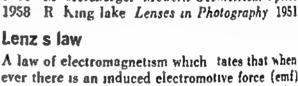
For higher magnifications many forms of magnifiers exist One of the basic designs has the form of a full sphere with a diaphragm at the center as shown in Fig 5*a* The sphere may be solid or it may be filled with a refracting liquid When it is solid the diaphragm may be formed by a deep groove around the equator Combinations of thin planoconvex lenses as shown in Figs 5*b* and *c* are much used for moderate power Better correction can be attained in the aplanatic magnifier of C A Steinheil in which a biconvex crown lens is cemented between a pair of flint lenses (Fig 5*d*)

A design by C Chevalier (Fig 5*e*) aims for a large object distance It consists of an achromatic negative lens combined with a distant collecting front lens A magnifying power of up to 10× with an object distance up to 3 in can be attained [M H]

Bibliography K Brandt *Das Photo Objectiv* 1956 M Herzberger *Modern Geometrical Optics* 1958 R Kingslake *Lenses in Photography* 1951

Lenz s law

A law of electromagnetism which states that whenever there is an induced electromotive force (emf) in a conductor it is always in such a direction that the current it would produce would oppose the change which causes the induced emf If the change is the motion of a conductor through a magnetic field as in the illustration the induced current must be in such a direction as to produce a force oppos



Induced emf in moving conductor Direction of current induced in wire AB indicated by the arrows (From M W White K V Manning and R L Weber Practical Physics 2d ed McGraw Hill 1955)

ing the motion If the change causing the emf is a change of flux threading a coil the induced current must produce a flux in such a direction as to oppose the change That is if the change is an increase of flux the flux due to the induced current must be opposite in direction to the increasing flux If the change is a decrease in flux the induced current must produce flux in the same direction as the decreasing flux

Lenz s law is a form of the law of conservation of energy since it states that a change cannot propagate itself *See* CONSERVATION OF ENERGY INDUCTION ELECTROMAGNETIC [K V M]

Fig. 2 Stig an w th tt h d n ts. (F m I W h A l t od ct t th St dy f Fo l Pl t A and C B k 1940)

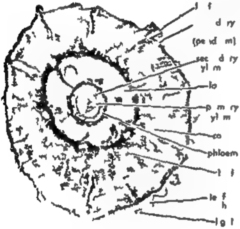


Fig. 3. L pidod d s f T t f the ste L cu f med by b eakd w f rt l t tue (F m M H l q R h h l L p dodendron sel g d St M m L é S N nend d ol 17 1892)

a h t zed b t m that be r ra ed d a mond h ped m und of t u called leaf u h n to hich the lea es e tta h d Th ord had a ld d t b t a d s t d fr m Late D thr gh P rmi n t m W llk w g ra L p dod d Lep d phlo S g lla a B th o d St gm ria L p d st bus L p d ca pon, Ulod ma, and U a p n

Vegetative morphology Th arb re ce t g ne a er l rg t ees (F g 1) me attain ng h ght in ex es f 100 ft. The ba al p rt e sted f d chotom t m f rh zomel k s c lled S gm ria, gi u g a ly h rizontal b hes at t b se f th t k These g s wh h bo e sm l d r oot (F g 2) had teml ke port e St gm an axes wer born by L p dod nd L p d phl B th od d n S g l laria, a d po bly th

The tall straight trunks u ually branched by un equal d hot my i t a n wn of s ccessi ely smaller br nche (Fig 1) *Sigill ria* howe er b anched ly slightly or not at all Anatom cally the stem (Fig 3) contained a l d or tubular c nt l strand of primary xylem urrou ded by pr m ry phl em Le f trace br nch fr m the s r face f the entral t and a d are frequentl ac compa ied by tw parenchym at u parichn trand of i know fu ct n In ma y species onda y xyl m and phloem were p odu ed Th e is freq i ntly a wide periphe al z e of elongated thi k walled cells prod ced by meristem tic a tiv ity w th in the rtex This second ry rte or pe iderm i the major upp ting ti in th arbo es ent pec es nc the ec ndary wood ac co nt f r only about ne-tenth to o fifth of the t tal bulk of the tem The in er c ti l tiss es frequently lacking *See* MERISTEM LATERAL STELE

Leaf cush ons re a p om nent fe ture of me gene a (Fig 4 5a) Tho e f m whi h leaves hav falle e sually chara teri ed by a leaf car a lig le p t a d in *L p dode dro* a v rtic l ridg be eath the leaf ar all d the keel (Fig 5a) Ab ci on f the l f i *Lep d phl os* and *S bl pid pl l* s d d n t oc r flush with the ur fa e of the cu h on but from an o tw d ten n all d the leaf ba (Fig 4) The long

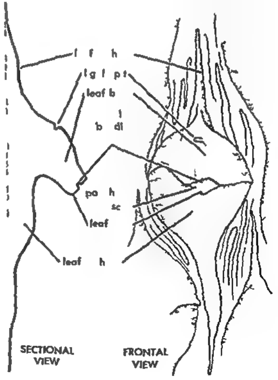


Fig 4 S bl p d phlo f o l f h s f l d f t l w (F m C A H pp g A t th l f h f p f P l o b t ly p d P Roy S Ed b gh B l 66(1) P tt 1 1956)

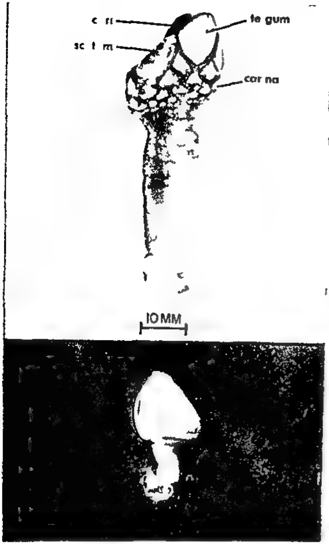


Fig 2 (Top) *M tella polyme s* Sowerby One of the prim t ve Lepadomorpha showing numerous lat al plates and calcareous scales on peduncle (*from D P H ry The C rr ped a of Puget Sound w th a key to the spec es U Wash Publs Ocea og 4(10) 1–48 1940*) (Bottom) *Octolasm s lowe* (Darwin) from the gills of a crab

Eight families are differentiated based in part on the number and structure of the plates The most primitive family Scalpellidae has more than five plates The other families have five or less plates which vary both in number from five to none and in size

Males occur in some species of Scalpellidae and Il lidae These vary from small replicas of the larger form to mere sacs Usually the least modi fied are associated with hermaphrodites and the most modified with females

Many species attach to floating ol jects or to motile animals others attach t fixed objects or animals often in deep water The species of one genus excavates burrows in calcareous rocks and coral One species approaches parasiti m in that the peduncle is deeply embedded in the skin of a shark *See* THORACICA [D P H]

Lepidocentroida

This name was proposed by T Morten en in 1934 for an assemblage of echinoids now regarded as polyphyletic J Durham and R Melville (1957) refer the included families to Echinocystitoida and Echinothurioida [H B F]

Lepidodendrales

Giant club mosses an order of extinct lycopods, consisting primarily of arborescent forms whi h constituted an important element of the Carbonifer ous flora *See* PLANT KINGDOM The group is char acterized by dichotomous branching by spirally arranged microphyllous leaves by the production of small amounts of secondary vascular ti ues relative to the total bulk of the plant (several pe cies are known not to have produced secondary ti sues) by the possession of a ligule and by heter ospory (bearing spores of two types) In at lea t two genera heterospory attained a level of speciali zation approaching the seed habit Several genera

F g 1 R st uct o of Lep d d nd o (F om M H me Ha db h der Pal b t k R Old b rg V l g 1927)

Th l pid de dral n g e a were mmon n habita t of the ten P n yl n an c l swamps nd f d c mm ly as fo il m l ball and in h les a i ted w th c l eams Se COAL BALLS PALEOBOTANY [C B B]

Bibliography C. A Arnold *A Int od t n to Paleob t y* 1947 J h W lt *A I t duction t th St dy f F il Pla t* 2d ed 1953

Lepidolite

A miner l f ari bl mposition th t i also call d lithium mic a d lith o te K (Li Al) s (Si, Al)O (F OH) R b d m Rb d cesium, Cs may r pl p t m K m ll am unt of M Mg Fe(II) nd Fe(III) rmally are p esent a d the OH/F t ar o ider abl P l thi n t a s l d l th m rich a d thus aluminum poor a ty f lepidolite

Lep d l t u mm lm t lu l m str ct ally mplex gr nitic pegm t te com aly in pl me t t C mmo a e qu tz, lea l dite lkal be yl d alkali t urm l Lep d l t s a comme cial sour of l th m, mm ly u ed d tly l th m gl es d oth am p ducts Important d po its oc r in the K ib b d tri t f S th W t Af a and t B k t Rhod a

The tru t l m d fi t how m rr l tion th lith um o te t th lay m n l f m c t n 40–51% Li O the o e l y m oclin 51 72 6% Li O A th ee-l y h go al f m lso f u d There s comp t o al gr d tw t m termed te types b lled l than m sc it c t g 3–4% L O d ha ing modified two-l ye m ocl m t struct

Lep d l t ally f rms mall s l r fi e grained ggreg t s It l p k l l e d gra a f ti n f th M /F r t It i f at 2, y ld ng th m (l th m) fl m It h a pe fect b al l g H d s i 25–40 per fi gr ty 28–30 Se MICA SILICATE MIN ERALS. [E W H]

Lepidoptera

Th de f aly w ged ts l d g th b t rfl es, skipp r a d m th Th s n f th largest o d in th l I t It ha m e th 100 000 p es ab t 10 000 N rth Am a d betw en 125 d 175 f m l e Th d lt h a e g f h s nd fl tt ed et e l o th wings, l gs a d body d oft b a t f lly l ed W th m r c pt th d lt a l hara t ized by tw p f m mb u w g d su k ng m uthp t f t g p m e t, led p bos f rmed by th g tog th f th m ll ry g l e M tam rph s m plet Th l r e, mm ly lled t p ll and bul t and cyl d l w th h t tho c leg d a bl mb of bd m l p leg They h o p f th r a d e ght p f abdm l les Pupa bl f m and h e appe d ge that a ually firmly ce m t d down (bt t) thou h th y are som t me tly or c pl tely free (rate) Pupae ften are encl ed n a silken c B tterfl e and skippers usu ll fly in the d yt m and most ths are noctu n l The adults u ally take l qu d f od such s n ct r and ju ce f fru ts The cate p ll a e alm t always he b

MORPHOLOGY

The m t unu al feature of the he d f th d lt anim l th f rm of the mouthp t The p b s- tended by blo d p e ted by the r tract on f the t p t f th ma illae D ago al muscles w th n h pr bosc unit cau e the pro- b ci to coil Th liqu d food sucked up by m s of a muscul pump fo med f om the phar ynx b l ty nd b m (f d p cket of th m uth ty) O ll r b t n many groups such as the Hesperioidea a d P p l n de A te re qu te variable i th Lep d pt

Thorax Th pr th ra i w ll developed i m l w g up such as the Hepial de but is consid rably m ll th the pt th ra i w g b segments and i l g ly membr nous in most Lep d pt ra Th mo t promi t fea t f th d um f the pr thora in most g ps p i of pr t b t le oti ed lob s or p t g I m b tt fl es the t tures ab t, d the pr th x n sts f cler t ed ng c e ted d lly to the m thorax by only a m ll pl te of the pr t m nd ent lly by the th n le t ed r bb f the pi t um

The f th p thora e cyl dr cal and f t l Th se of th pt thorax f ed with th th c e cap ul nd imm b le In ea h eg m nt of th th th m d e t l utur the d cri me p nt d internally by a th n pa t lam The conf m t n f th l m lla d ts r l t n h p to th f esp lly i the mes tho- p d t be h ter f c d bl y t m t c l n the b tt fl It i k w to ry the m th b ng l w in th m l ed g p Th m th i the l t of th th e me ts d may mpl t ly e l p th m t th

The e t n d abl t n th o ho t th d the d t l f th t es nd l tes of th nt ment l t my I th b tte fl e t t t h be n f u d th t u tur f the g t b t th h t b t d d n th e t f th o d

Wings I m t m th th w g pled by gle p f rm d by numbe f fu d et e u lly g m les g o p f s t lly f d in f m le wh h p j t f wa d f m th b f th h dw g d e h ld by la p th f ew Th p e k w a th f l m d th l p th t l m I th H m u th l b th j g m t th b e f th f w g wh h g g th h dw g th f l m

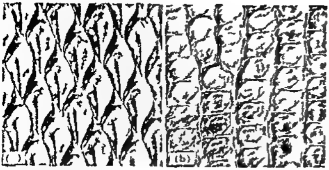
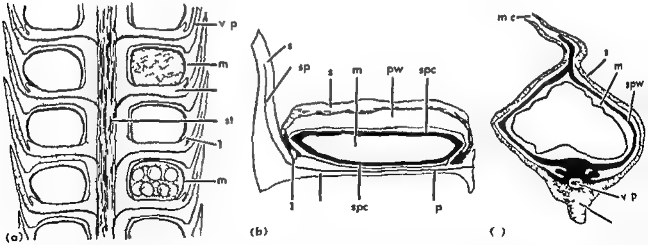


Fig 5 Stem compress ons showing leaf scar a range ment in (a) *Lep dodendro aculeatum* and (b) *S g ll a boblayi* (From A R nier F Sto kmans F Dema et and V Van St a len *Flore et Fauna Houillères de la Belg que* M seum Roy H t Nat Belgique 1938)

axis of the cushion in *Lepidophloios* is horizontally oriented in contrast to the vertical orientation of *Lepidodendron* Some genera such as *Bothroden dron* and *Sigillaria* either lacked leaf cushions (Fig 5*b*) or bore slightly rai ed ones Stem com pressions of *Sigillaria* (Fig 5*b*) are easily dis tinguished from *Lepidodendron* (Fig 5*a*) by the arrangement in the former of leaf scars in vertical rows

The linear to awl shaped leaves varied from about 1 cm to 1 meter in length and usually con tained a single vein However leaves of *Sigillaria* which also attained the greatest length may have always contained two veins at least in their bases On vegetative parts of these plants the ligule a small unvascularized appendage was located above the leaf in a depression called the ligule pit (Fig 4) In strobili the ligule was located on the sporophyll just distal to the sporangium (Fig 6*a*)

Reproductive structures The Lepidodendrales were heterosporous Strobili named *Lepidostrobus* were produced by *Lepidodendron* and *Lepido-phloios* *Lepidocarpon* by *Lepidodendron* and *Bothrodendrostrobus* by *Bothrodendron* *Sigillario-strobus* and *Mazocarpon* were strobili of *Sigillaria* The plant which bore *Miadesmia* is unknown *Lep idostrobus* was bisexual containing both mega spores and microspores (Fig 6*a*) *Lepidocarpon* produced either all microspores or all mega pores The horizontally elongated megasporangium (Fig 6*b c*) was enclosed by the sporophyll ometimes called an *integument* *The cavity formed by this* integument had a slit opening (micropyle) along the upper surface One of the four mega pores developed into the gametophyte the remaining three atrophied Archegonia have been observed in the gametophyte and microspores di covered within the sporophyll Presumably fertilization occurred while the gametophyte and porangium were contained within the enclosing porophyll but no embryos have ever been found The truc tures are frequently called eed although there i little evidence that the so-called integument more than a highly specialized sporophyll *Miadesmia* produced e en more highly specialized eedlike structures *Mazocarpon* differed from *Lepidocarpon* in producing eight megaspores everal or all of which were functional embedded in a mass of par enchymatous tissue The *megasporangium* and sporophyll were shed as a unit *Ma ocarpon* and *Sigillariostrobus* (a compres ion fossil) are prob ably synonymou and were borne laterally on the trunk or large branches of *Sigillaria* The trobili of *Lepidodendron* were probably always borne terminally

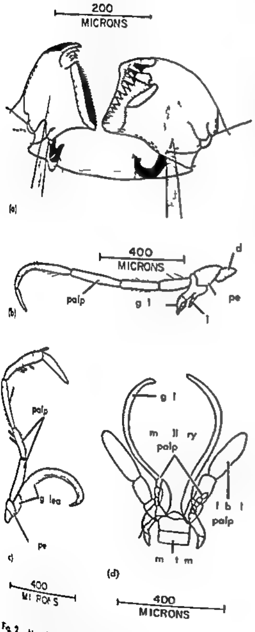


F g 6 ( ) *Lep dostrobus* Ideal zed d aw ng of a lo g t d al section of part of strob lus (From C A Ar old *An I trod ct o to Pal obota y* McG w H ll 1947) (b) *Lep d ca pon* oe se r con truct on of a spo ophyll and spo a g um c t away along a med a long tud nal plane d (c) cut at a r ght angle to the long s Key l l g le m meg pore me mega po rang m conta ni g meg spores m m c spo a gium conta n ng m cro p s mic mic pyle; s sporophyll spc ca ty of p a g m; spw sp ra g m w ll; sp ascular upply of spo phyll; vst asc lar supply of t b lus a s (From J H Ho k s a d A T C o s *A co s d rat o of the str ct e of Lep d ca p S ott b d o a ew st b l from I w* Am M dla d Nat al t 25 1941)

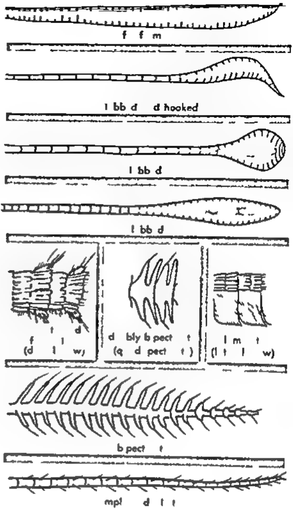
Genitalia The f m f the e te l genitalia sec ll that f th mal ha bee w dely u ed n the separati f spec es

DEVELOPMENTAL STAGES

Egg There are t o g e al type of e g flat tened d up ht I both type the surfa is usu all sc lptu ed a d th culpt g f tl p ght tre g lly m e c mplex Th e is a m c o-scop entra e for th perm the mi r pyle The eggs are ally la d n th f od pla t either s gly



Fg 2. Mouthparts f d lt H m of Sabat inco g ll W lk (M pt rygd) Ma lla f Mi ropt ry ll S p (M p-terygidae) ( ) Ma ll f E cr m p p ll Seph (E ocra id) (d) M ll d l b m f Hinearch ea pa sm M y k (M sa h d)



Fg 3 Typ f L p d pt t

or n l te They e n rm lly att hed by a c m t b t m y be m ely sc ttered i the c ity f the fo d pl nt

Larva Th e a q te able i p fi ial cha ct ch c l r st a d h pe p e e c of w t ha d et e r n m nt f hook or o h t the p ol g d othe m n det il but e th t nt n b ic m rph logy Th e su lly 6 pa s fo ll nd mp nd ye e li t At m t 8 p r f p leg e p e nt b t lm st ery d e f red ct n i f u d The l n mb s 5

S lk p od ed by th l bial gla d Th y l g c led mple tub s wh h u t a t rly yl d cal pi t wh ch t the f t f th lab m

Pupa Th e thr e types but the st m jo tv e btect w th pp dages f te ed d wn d mm b le d w th only th t m al abdom l eme ts m bl Th of th H p l id C s de a d me the l wer m th i compl t n that th abd m l egm nt eph l d f th f th em bl The ppe d g r partly f ee b t h thed Th M c pteryg dea a d Er ocra i d ll e f e pup wh ch th ma d ble

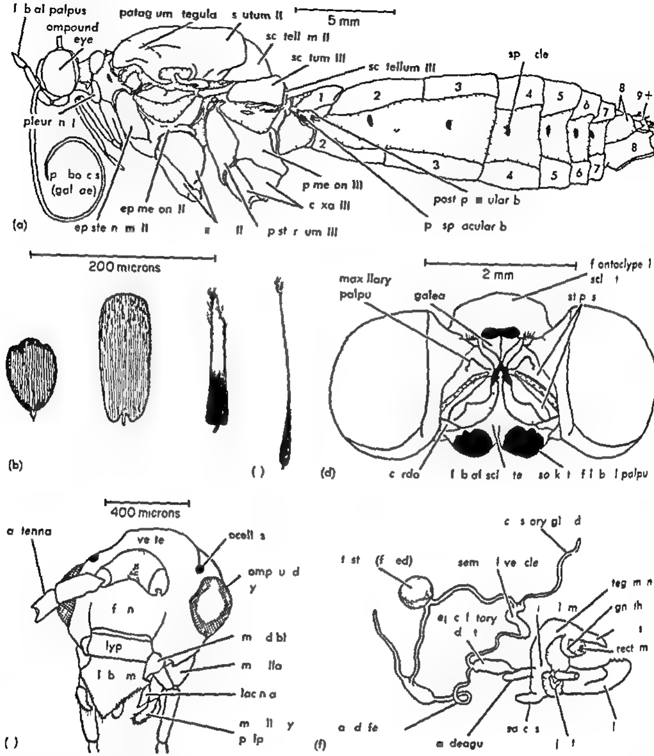


Fig 1 Ad lt Lep dopte anatomy ( ) Lat ral ew of Danaus ple ippus L (Nymphal d e) w th est t re w ngs and pterothorac legs remo ed (b) U special ized scales (c) A d ocon a (d) Vent l iew of head of D plex ppus L (e) Fro t ew of head of Ep morty a (M cropteryg dae) (f) Mal ge tal system (d ag am mat c)

when it is pre ent In some of the higher moths skippers and butterflies the humeral angle of the hindwing is expanded and trengthened l y one or more humeral veins In the e group the frenulum is usually lo t and the wings are coordinated by the overlapping lobe

The cales are very variable in form Cenerally they are flat thin sclerotized sack with striated outer surface They have a basal pedicel which fit a cket in the wing membrane In the males ome cale the androconia have feathered tips which serve for the dissemination of scents The n t spectrum of col seen in the Lepidoptera can l e grouped into two categ rie pigmentary and truc tural color Pigmentary colors re ult from g ments which are pre ent in tl e scale Structural colors are the re ult of either fine surface ridge on the scale or layers within the uticle which inter fere with or diffract the l ght The structural col are generally metall c or iride cent

Genitalia The form f the ternal ge talia e ecall t of the m l h bee w d ly used in the separati f pecies

DEVELOPMENTAL STAGES

Egg Th e tw ge eral types f egg flat tened a d p ht. I both types the rfac u u all sculpt ed d the lpt of the p ght tree generally m c mple The e is a m c o-scop t an e f the p rm the m pyle The eggs are u ll l d o the food pl nt eith ngly

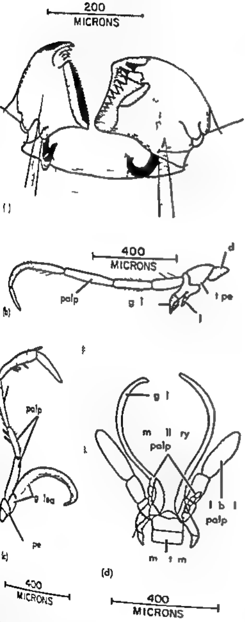


Fig 2 M thparts f d lt H m f Sabatinc inco g ll W lk (M pt ryg d) ( ) M d bl ( ) M Tla f M ropt ry ll S p (M p-terygidae) ( ) Ma ll f E io m p ll (Eriocraniidae) (d) M ll d l b m f Mnesarch eo p cosm M y k (Mn sa E d)

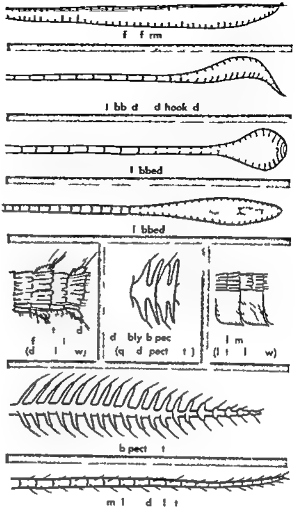


Fig 3 Typ f L p d pt a t

i clu ter They re normally att hed by a m t b t m y be me ely tte ed in the v cin ty f th food pla t.

Larva The ar q ri ble in s pe fic al hara te s h a col e d h pe p en e f w rt ha a d ta ar geme t of h oks ch ts the p leg a d th m n d t ls, b t e th t nt in b m ph l The u lly 6 p i f c ll d omp nd ve are b e t At m t 8 p s f p ol g ar p es t but lm t every deg of du t n f d Th al umbe 5

S lk i prod ed by th lab al glands They l g o l d mple t bes whi h un te nte l rly in a yli d al pi n t wh h p at th f ont f th lab m

Pupa The a e thr e type b t the a t m j ty e obtect w th appe dage f te ed down d mm b le d w th o ly th t rm l abd mi l gme ts mo Tho e f th Hep l id a, Cos de d m othe lowe m th re n omplete, that the m al s gm nt e phalad f th f th m ble Th appe d ges e pa tly f ee b t h thed The M pt yg de d E ocr n d h f ee p p e wh the m nd bles a e

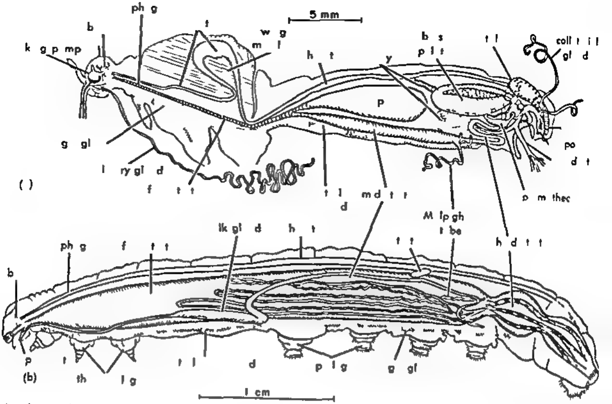
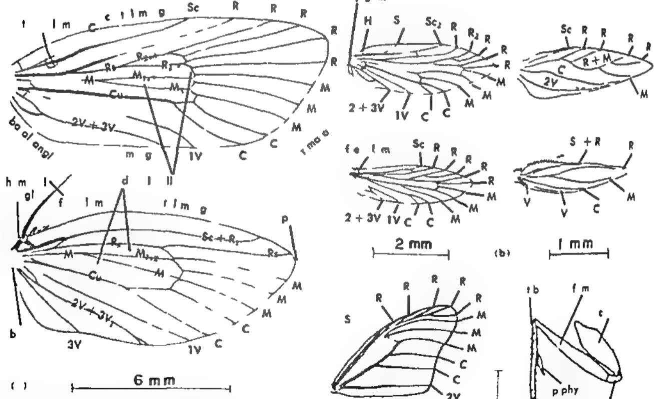


Fig 4 Internal anatomy of *D ple ippus* L (Nym phal dae) tracheal system and most of musculature omitted (*a*) Ad lt female (*b*) Larval male



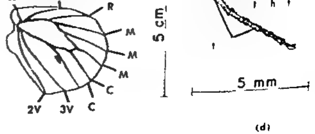
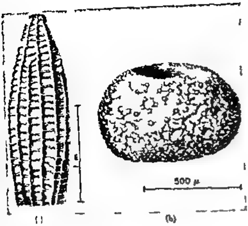
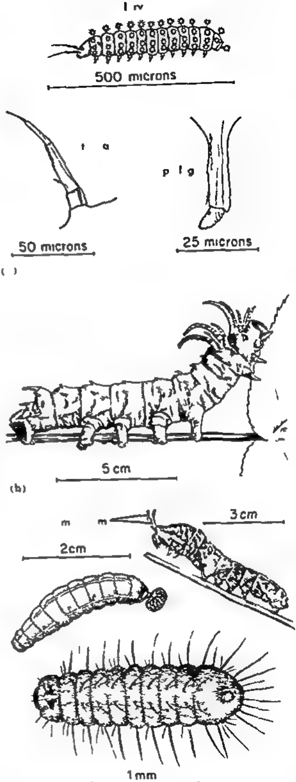


Fig 5 (*a*) W ngs of male *Acrolophus popea ell* Clemens (T ne dae) w th veins labeled (*b*) W g vena t on of Ep martyr a (M cropterygidae) and *Nept cula nyssaefol ella* Chambers (Nept cul dae) (*c*) W gs of [redacted] *ple pp s* L (Nymphal dae) C costa; Sc subco ta; R rad s R rad al sector M med a C c b t s 1V 2V 3V vannal vei s H humeral ve n subscr pt refer to b anches (R_2 is second b a ch f ad s) (*d*) P o tho ac c leg of *Pap l o* (P p l on dae)



Fg 6 Eggs of butterfl s. ( ) *Strym* d co Ed wards (Lyco id) (b) *A th* *m d* H b Pieridae)



Fg 7 ( ) N wly h t h d l rv f M pt ry *col th lla* L. (M pt ryg d) (b) H k ry h m d d l l rv f *C the* g l F b (S t m d) ( ) Sk pp d b tt rfly l rv M t *Th ryb pyl d* S dd (H p d) M t *P p l* s- *ph t* Cram (P p l d e) w th m t m t d d F t i ta *Strym l pa* Bo sduv l a d I t (Ly d)

fractional the appe dages f h ad thorax and segments of the abdome are mo able and th in tegument is soft.

CLASSIFICATION

The Lep d ptera re long d ided into tw s b- ders, the Rhopaloc w th clubbed a te ae such as b tterfl d kippers and the Hete - cera, th a te e f other f rms in the m th and millers. Th butterflies a d kippers form a maj r nat al u t, with abo t 10 000 species and ften f rr d to a th ies Rh p lo ra Th e ha d h t my n th de h weve app ars to be bet een the Hom eu d H te o eur and these ubo d a e rec gn ed h

Th t rm M ol p doptera and Micr l p d p- tera often ppea n zool g cal lite t e as name l f rn r d Th m rolep dopte a the Hom neur d th s p fam lies I curva d a through Pyr l d d of th Heter ne whi h a e generally m ll m th The m r lep d pt a e the larger m ths a d butt fl es Some m lep doptera, h a m ny ds hepi l d and ers, e m ch l g th n ma y m c l p d p- tera.

I f rtun tely th l fic tio of th Lep d p- tera is th s bject f c derable o tr e y e h ll d btless be es l ed when m e m k f th n t my a d l fe h t ry f many gr ps. Beca se f th e d ffi lt e th d agram of l h ps is at best p I

A r h servat l ficat n ha been u ed b- It m la to th t f C. L. Rem gt n (n E s, M l d d Carp t r) cept th t th c tio of th P p l d a f ll w P R E h (1938) I m ny perf m lies ly th er import nt f m l es a me t ed

Suborder Homoneura (Jugatae) F e- d k g e m l s h pe d e ti n They con ected by a j gum a d som times lso by a fren lum. M thp rt a ma d b l t w th m n d les st l bse t d th g lea f rm

Table 1 Important famil es of Lepidoptera

Clas. ification	Common name	Di tril ution	No of pecies
Suborder Homoneura			
Micropterygidae	Micropterygids	Holarctic and Au tralia	3 (3)
Friocraniidae	Friocraniids	Holarctic	[illegible] (0)
Mnesarchaeidae	Mne archaeids	Ne Zealand	
Hepialidae	Swift or ghost moths	Cosmopolitan	18 (00)
Suborder Heteroneura			
Incurvariidae	Yucca moths and relatives	Cosmopolitan	60
Nepticulidae	Serpentine leaf m ners	Cosmopolitan	
Cos idae	Goat or carp nter moths	Co mopolitan	45
Aeger idae	Clearwin moths	Co mopolitan	1 0
Coleophoridae	Ca e bearers	Cosmopolitan	110 (900)
Gelechiidae	Gelechiids	Co mopolitan	590 (3800)
Gracila iidae	Gracilariids	Cosmopol tan	3
Heliodinidae	Heliodinids	Co mopolitan	1
Oecophoridae	Oecopho ids	Co mopol tan largely Australian	(3000)
Orneodidae	Many plume moths	Cosmopolitan	1
Psychidae	Bagworm	Cosmopolitan	
Tineidae	Clothes motl s and relatives	Co mopolitan	135 (00)
Yponomeutidae	Frmine motl s	Cosmopolitan	6 (800)
Olethreutidae	Olethreı tids	Co mopol tan	15 (00)
Tortricidae	Tortricid	Cosmopolitan	10 (1 00)
Thyrididae	Window win ed motl s	Tropical	10
Pyralid dae	Pyralids snout moth	Cosmopol tan	113 (1 000)
Pt rophoridae	Plume moths	Cosmopolitan	130
Eucleidae	Slug motl s	Co mopolitan	50 (900)
M galopygidae	Flannel moths	Mo tly Ame ican a few African	11
Zygaenidae	Fore ters and burnets	Palearctic Af ican and Indo-Australian	
Ca tniidae	Castniids	Neotropical and Indo-Au st al an	
Drepan dae	Hooktips	Holar ti	6
Geometridae	Mea r n wo ms loopers canke worms car pet wa es and pugs	Cosmopolitan	1 00 (1000)
Uran idae	U aniids	Tropical	
Sphingidae	Sph nx l av k or l um min l i d motl s	Cosmopol tan	106 (1000)
La ocamp dae	Te t caterpillars lappet moths	Co mopol tan except New Z alan l m inly tropical	30 (1400)
Saturni dae	Giant s lkworms	Cosmopol tan	60
Bombycid e	Silkwo m and allies	Tropical	1 (i tro luced)
Arctiidae	Ti e moth	Co nop litan	00 (3600)
Lymant iidae	Tus ock moth	Larg ly Afri an and Indo-M layan l t with mport nt Hola ct c pec es	
Notodo itidae	Prominent pu s moths	Co mopolit n e cept New Zealand	1 0
Noctuidae	Noctui l owlet un ler wings mille s	Co mopolitan	700 (0 000)
Hesperiidae	Skippers aga e worms	Cosmopol tan	10 (3000)
Papili nidae	Swallowt il l i d ings pa na in	Cosmopol t n	(600)
P idae	Wl tes ulf rs ora tips	Co mopol tan	61 (1000)
Nym phal d e	Fou footed l utt fl es	Co mopolit n	11 (000)
L l yth lae	Snou t l utt rfl s	Cosmopol ta	1 (1)
Lyca n dae	Blues coppers l a r streak metal ma k	Cosmopolit n	138 (3 00)

The first f gure i tl e number of l scr bed pecies n N rtl Ame ica no tl f Mexico Tl i f gu e re ac ur te The second f gure in parentl e i wl en p esc t i ough estim t of tl e n l r f lesc ibed pe in tl e worl l It i difficult to postulate tl ct al t tal f Lep l t a species from tl se f gu s g ce t groups u h a tl Papil onidae probabl y n tl 90 of tl x t g sp es ha lee lesc bed wl l otl rs ch a many fam l es of m rolep l t ra tl f gur may be w ll n ler

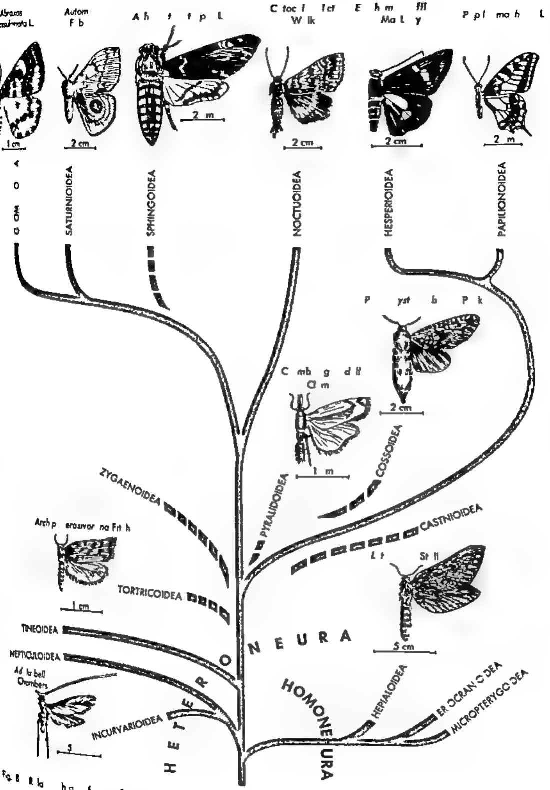


Fig. 8 ... h p f p rf m l f L p d pt

... The fem l ha gle ... m tu e f rm h w g rt fe t m
... pen g The p pa r f e r p t lly f m w th th T ich pt dd fl
Th m ll ubo d l d ng l s th ... f *S p f m ly M pt yg d* O e mall f m
... th d nt d g p f ly th M pt yg d m t m th p s-

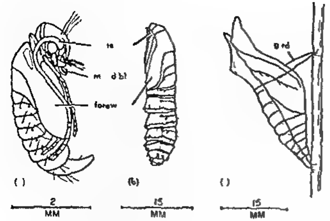


Fig 9 Pupae (a) *Mnemo ca au icya ea* Walsh ng ham (E iocraniidae) (b) *Sthenopis thule* Strecker (Hep al dae) (c) *Pap l o t o l s* L (Pap l on dae)

ing toothed functional mandibles and lacking even the mo t rudimentary proboscis The galea of the maxilla is short and the adults feed on pollen The larvae *which feed on mos e are unusual in having* eight pairs of abdominal prolegs

It has been suggested by various authoritie that these moths are actually terrestrial Trichoptera or that they should be placed in a separate order Zeuglоptera Characters of the wing venation tra cheation the presence of broad well developed scales with numerous ridges and other features in dicate that these insects are best included in the Lepidoptera

Superfamily Eriocranioidea In this group of tiny moths the mandibles are greatly reduced and un toothed and the galeae of the maxillae form an ab *breviated probo cis Three families the Eriocrani* idae Neopseu tidae and Mne archaeidae have been recognized *within the superfamily The leaf* mining larva is essentially apodous (lacks legs) The adults reportedly do not feed The females have a piercing ovipositor

Superfamily Hepialoidea These are medium to large sized moths which po se s rudimentary mouthparts The larvae are borers The rapid flying adults are mostly crepuscular thus the common name swift or ghost moths The only family of im portance is the Hepialidae which has about 200 species The Nearctic species belong to the genera *Hepialus* and *Sthenopis See* ZOOGEOGRAPHY

Suborder Heteroneura (Frenatae) Fore and hindwings *are markedly different in shape and* venation Usually they are connected by a frenulum and retinaculum *Mouthparts are haustellate* (formed for sucking) or rarely are vestigial Adults with functional mouthparts feed on nectar of flowers juices of rotten fruits and other liquids The female usually has two genital openings Pupa are usually obtect

Superfamily Incurvarioidea One family the In curvariidae comprises the superfamily The wings are covered with micro copic spines or aculeae and the females have a single genital opening as in the Homoneura The venation is almo t complete The *basal segment* of the antenna is not enlarged to form an eye cap The larvae are eed leaf tem or *needle miners In the* subfamily Incurvariinae the larva is first a miner and then a ca e bearer The pupa is not completely obtect

This superfamily includes the famou yucca moth *Tegeticula* (=*Pronuba*) *yuccasella* Riley This small white moth has an obligatory mutualis tic relationship with the yucca plant The female *gathers pollen with its specially adapted mouth* parts and fertilizes the yucca flower The eggs are *laid in the plant ovary* by means of a piercing ovi positor the larvae eat some of the developing seeds

Superfamily Nepticuloidea One family is in cluded the Nepticulidae These tiny moths have wing pines and the females have a ingle genital opening but they differ from the Incurvarioidea in *having a reduced venation and a large eye cap at* the ba e of the antenna The larvae with the excep tion *of some gall making species of the genus Ecto edemia* are miners in leave bark and rarely in *fruits Many species of the genus Nepticula* have a wing expanse in the 3 to 5 mm range being the smallest insects in the order

Superfamily Cossoidea One family the Co idae commonly called the carpenter or goat moth ar heavy bodied moths with the abdomen extendin well beyond the hindwings Mouthparts are rud mentary except for labial palpi The median ve (M in Fig 5) stem extends to the base of the win and is forked within the di cal cell The larvae ar borers often tunneling in the hard wood of tre trunks *Prionoxystus robiniae* Peck is the be known American species It is very destructi e to *large variety of deciduous trees*

Superfamily Tineoidea There are 1(–39 families the number varies *with the author This is a ver* large group of uncertain compo ition These m th are of small size usually with *well developed max* illary palpi The labial palpi have a slende pointed third segment In the hindwing the ul co ta and radius (Sc + R) are free or are joined to the cell by a bar Venation may be reduced and the wings may be divided into plumes

Aegeriidae is the family commonly called the clearwing moths becau e of the large transparent scalele s areas on the wings The Sc + R_1 vein in the hindwing is apparently absent but actually it is concealed in a costal fold Many specie are *excellent mimics* of wa ps They are diurnal and often l rightly colored Many of the l oring larvae *are economic pe ts* Among these are the currant borer *Ramosia tipuliformis* Clerck the peachtree borer *Sanninoidea exitiosa Say and the s* quash vine borer *M littia satyriniformis* Hul ner

Cole phoridae are small narrow winged moths who e larvae are case bearers carrying "shell" made out of silk *and l its of lea e The adult* lack maxillary palpi

Gelechi dae *is a large family of minute to* mall moths usually with rounded or rarely pointed forewings and *trap ezo dal often pointed hind* wings Venati n i arial le and s metime reduced

h R radial ect r and med a M of the hind ing are stalked or cl together at th b e The arvae incl d seed feede mine s b rers gall kers d fol g feed The f m ly includ a umber f ec nom c lly impo t t insects The ingo o s grain moth, *S t t oga cere lella* Oli ier of is gr t both in th ll ld and i st The k boll orm *P ctinopho a g s ypi lla* Saund is extremely imp t t w ldw de pest of t on.

Gra l rud e are small moths w th l af mining arvae Both pai f w g a e la ceolate d d ly fri ged Th y g larv e a e fl tt d and have bl d l k mand bles w th whi h they la h the h f the le f, su kin p the ex ding ju ces The full-grown larvae e quit d ffi t bei g n n m appear e a d feed ng on pare hyma ether in a l f mine externally The be t kn wn genera are *G cil* and *L thocolletis*

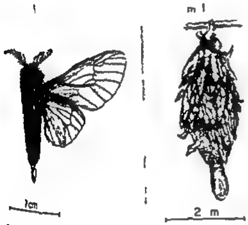


Fig. 10 *Thy d pt ry ph m f m* H w rth (Psychidae)

H lod d is a m ll f m ly of tiny m th hich are oft n b ll tly c l r d A n mb of gene ch a *Stathm p da d Euclem* n the pecies wh e larv tt ck ds

Orceoph dae m ll t m d t ly m ll moths th a n mb of b tle th p ten n the ware of th ant s Th larv e r ed h b- its som feed eb lled l a es th eng r or p ed to d The g n a Rec. bous *H l oc* a d the e ft n pl ced in a separ t f m ly the Bla t b id e *Hol a* r M r k a imp t t p ed t o th ke m ect Ind a

Oraeod d e s m ll f mily wh se d lt ha each wing d ded nt s x f the l ke pl m s S me authors pl c th m in th Py al d idea w th the Pterophorid e, but the m j rity bel th t the re- semblance betwee the t fam l es i a a of convergen

hid are the bagw m Th m le a hairy stro g bod ed wift fly g moths w th e- ed mouthp rts. They re l rg w th w g x panse of about 25 mm f r the ti eoids The f males are degene ate w l l gle and often slugl ke They live concealed n b g h p d ca es m de by the caterpill The b t known North Ame c n rep esentat s *Thyrid pte yx ephemer efo m* Ha rth In th p i the larva fa tens the bag to tw g and pup w th t The ermiform fe- m l m g f m th p pa a d m to the bot t m f th b wher h i fertilized Thi i complished from the outside by the highly special ized extru ibl genitali of th m l The f male deposits he eggs in the bag then drops to th gr d nd d

Ti e da i f m ly f m ll moths which usually has an erect b tl g v t t the head Th proboscis i educed or v t l nd the maxillary p lp usually well developed Th n t n is ge rally p m t w th m st eins bei g p e ent a d unstalked M t l rv e sap ophagou and m ny e ca e bearer The b t k wn specie the cl th moth wh ch include th m king l thes moth *Tin a p ll ll* L. th w bbing l th m th *T la biss ll lla* Hummel nd the c pet moth *T ch ph t petzell* L. These imp rt t p sts who l rv de ur wool and th animal p d ct The thre p c es all ha e wi g e p f le s th n nch

Yp nome tid heterog ne ass rtment f small ft n h ghtly c l d moth wh h u lly smooth he d d ed d o ab e t cell

S p f m ly To t c d Thes mall w de- w ed moth b l g t tw f m l es th Oleth u t d e a d th To tri ida The m xill ry palpi a e e t g l ab t nd the th d egm nt f the l b l palp is short nd usually btu I the h dw S + R ont guo with the cell nd th d ge f m R The h f g of th w gs ar lway h rte than th w dth f the wi

Olethr ut d is a fam ly of m ths who h nd w g u lly ha fringe f l ng hair n the pper d long th b sal p t of th b tu Th larv are gen lly h dd n fe der nd l e in oll d l a es f l w bbed t geth in d fr t The f m ly co t ns a numb of g i lt ally und sir bl pe i Param u m ng th se s th odl ng moth *C p p a pom ll* L. wh ch i very s p t of pple d the f u ts Th l ge g u *La pey ia* c nta n th int re t g M ca j mp bea m th *L lt t ns* West w d The l t m em ts f th larv f th m th e esp bl for the ti n of th b n wh l th y i h b t

Tort d e i f m ly wh ch g n lly l th f ge f l g h i l ng the bitu h ter s t f th Ol th t da Th u e budworm *Ch ist n f m f a* Cl m i p b bly the m t mp rt t j o t rt d In m y pl c pe lly E t rn C ad it ha d fol ated t of fe f t

S p f m ly Py l d d These moth ar m de t lv m ll t med m ed l g legg d d lend bod ed S + R f th h dw ng i lm alw y tted f c d ble d t n e w th R

The maxillary palpi are usually well developed

Pyralidiidae is the second largest family of moths They are small and medium sized with a wing expanse of 20–35 mm being not uncommon The labial palpi are well developed and the broad vannal regions in the hindwings often have three vannal veins The legs are usually long and slender

The subfamily Crambinae the snout moths contains small forms which are common in marshes and grasslands The labial palpi are quite long and porrect giving the adults a beaked appearance

The small subfamily Galleriinae contains the bee moth or wax worm *Galleria mellonella* L which lives in beehives The larvae feed on the wax at night and destroy the combs The species occurs throughout the range of the honeybee

The subfamily Nymphulinae is notable because ome of the included species are aquatic Some larvae develop tracheal gills others do not In some species the pupa is enclo ed in a cocoon below the surface of the water and the adult emerges from the water

The subfamily Phycitinae is a large group of moths in which the frenulum of the female is a simple sp ne rather than a bundle of l ristles The larvae have very diverse habits being leaf rollers case bearer l orers stored products pests and o on One species is predacious on coccids The Indian meal moth *Plodia interpunctella* Hubner is described by A D Imms as one of the most important economic insects known The species is cosmopolitan feeding on a wide variety of stored products especially cereals Another extremely important pest in this group is the Mediterranean flour moth *Ephestia kuehniella* Zeller which infests cereals throughout the world

In contrast to these harmful species the Phycitinae also contains *Cactoblastis cactorum* Berg which was imported into Australia from South America to help control *Opuntia* cactus which had spread rapidly to cau e the ruin of millions of acres of pasture The success of this program is an out tanding example of biological control

The subfamily Pyralidinae reaches its richest development in the tropics *Pyralis farinalis* L the meal moth is a cosmopolitan pest of stored products

The subfamily Pyrau tinae is another very large group It contains relatively large moths many extending 30 mm or more in which vein R of the forewing ari es unstalked from the cell To thi ubfamily l elong the infamous European corn borer *Pyrausta nubilalis* Hubner the grape leaf folder *Desmia funeralis* Hubner and other ec nomi ally important pecies

The ubfamily Schoenl inae includes the genus *Acentropus* the mo t completely aquatic Lepi lop tera One form of female adult never emerges fr m the water it u e it reduced wings f r wimming

Pterophoridae i the family kn wn as the plume moth The wing are di ided into featherlike plume of which there are u ually two in the fore wing and three in the hin lwing a in tl e tine id Orneodidae The moths lack maxillary palpi ha e slender bodies and long legs The larvae feed ex posed or are borers

Superfamily Zygaenoidea These moderately small to medium sized moths have complete vena tion rudimentary palpi and usually a rudimentary probo cis The wings are broad with hort fringes In the hindwing $Sc + R_1$ is eparate from R b yond the cell The larvae are short m re or le sluglike and are expo ed feeder

Eucleidae are the slug caterpillars a mall fan ily of heavy bodied hairy moth the larva short and sluglike with a large head concealed l the thorax The prolegs have l een replaced l y mi ventral suckers The be t known Nearctic form the saddleback caterpillar *Sabine stimulea* Cl mens which has urticating hair

( ) (b)

Fg 11 *(a) Platypt l a ard d ctyla* R ley (Pte phorldae) *(b) P ol ma des bad a* H bner (Eucle dae

Zygaenidae is a diver e family of mall ofte brightly colored m th in the ul family Himant pterinae which is primarily African The hinc wings are very narrow with long ril l onlike tail and the body and wings are covered by long l air The larvae of this ubfamily li e within termit colonie and the newly emerged moth e cap from the ne ts under the attacks of the termite The hairs pull free readily and tl e tail are ex pendal le

Superfamily Castni idea One family the Ca niidae is included in this group They are large diurnal butterflylike motl witl clul l ed antennae upright egg and boring larvae A prol o ci ma be either pre ent or ab ent The e moth are c n sidered by ome to l e di tantly related to tl e l t terflies but the re eml lances may very well l e d to convergence They are found in the Ne tr pica and Indo Au tralian regi n

Superfamily C ometr idea Tl e e are mall t large moth with reduced maxillary palp i an l tym panal organ at the ba e of the abd men In tl f rewing the l a e f the media M is u ually abo the ame di tance fr m the l a es of M an l M_3 anc tl e vannal eins 2V an l 3V ana t m e t f rm l al f rk The fren ilum ma l e present r al ent

Geometridae include tl e n a uring w rm l oper an l cankerw rm wl icl c mpri a very large family of mall a l me lium iz l m tl with lend r bodies and relati ely l r a l wing Tl f

ales are occ lly pter The larvae h e t ant n r p leg red ced or ab ent u ually ly bse n segme ts 6 a d 10 are well de l ped hey proceed th a h te t c loop ng moti n hch the b s for th sci t fic n me The l dinaril a e expo ed f ede s b t they ome me h e m f lded lea es a d often b r a t iki g semblan e to t Th s r enh nced by their habit f esting th the bod h ld r d at an a gle a th b a h hil h ld ng n with the t rm l p legs Pupat t kes pl ce n th gr und r a eak silken cocoo

Amo g the ec m lly imp nt Nea ct c geometrid ar the p a d fall k rworms *Pal nta t ta* Pe k and *Alsoph la pom tari* Harr h h att ck a l rge r ety f t ee Al f interest *Ste h bo fat* Hul t (=*E pt l* ennal) the herb i m m th wh e larva ar pests to lect f d ed plants

Urani d t pi al fam ly that in lude me moder bod ed, brill tly c l ed d urnal ns ts hich la k a f enul m a d re fte m st ke f erflies. The m ltiple-t iled m tall *Ch y d gas n s* Les on f om Mad g ca r me ered by m y to be th mo t b utif l l pi d pte a Th l rv e a d e i f rm b t h e complet set f p l g

S p f ily Sph go d a Sph n Hawk Hum ng b d m th c t tute th n f m ly Sphi gi d They a f med m z to ery la ge he vy bodied m th w th e t mely pid fl ght The ad lt m tly p cula r n ct rn l but few gen a a ed rn l The a ten ae e th ck ned and ha po ted ape Th p b i w ll dev l ped, and oft n xtr m ly l ng The wi gs tr a th th h ndwi g much h t th n the f rew g The f nul m i p e e t l th h d ng Sc + R is nnected to R at the m ddle f cell by a t g en d rem s p all l t t, n least f th nd f th c ll Th larvae e ternal feed and ally ha e ch r ct ri t adal h rn. The pupa r a ll i th gr und or a k we ocoon at the u fa d t l g p b s- ts ften n a project ng e embl handle

On f the m t widely d t buted p c es i the t l ed ph nx, *C l n l t* Fab c s Well k wn also i th Old W rld de th h d ph n *A t r ar p* L. Of ec mic importa c ne West rn H m sphe a the t m t h rnworm *Pr t us* (=*P ot p c l q q m latu*) F orth a d the t b c h rnw rm *P s xtus* Jo- hanson both f wh h a pest f l eou

per f mil Satu d Thes med m ed to ry l g m ths w th the frenul m alm t t ed ed r b t The s tymp n m e d th m thp rt ally ed ed Th ternae a d l pect t espec lly th

l amp d a e m th h h m y be ep d from th S t m d l th p e f p r mag h m l s t the h dw gs Th

w desp ead largely t op c l f mily cont ns the fam lia tent cat pill s of the g nus *Malacosoma* I this gen s th larv e l e t eth m la ge lk web n sts Tho e f *M ame ic na* Fabr us e a mm n sight tr e a d sh ub n the e tern U ted Stat

Saturn ida are th gi nt s lkw rms whi h are med um zed to extr mely large m th hav ng a ingle ften weak h mer l n The m uthpa re red ced r sti l and the ant nn a e t ly b pe t nate The r mi of th mal antenn e are co p cuo ly l nge th n th s f the female The frenulum s ab e t The larva us lly be p y p c se known s coli P pati n t kes plac i larg silken c ns whi h sp nded from twi r formed n l af l tter n th gr und

Atta us duardsi Wh te f Au tral a *A tlas* L. f the H mal ya fo th ll and *Cosc s e a h cu l s* M sk n of A t al re ch an exp n i the fe- m le f mor th 10 i They ha e the la ge t wi g ar s i the I ect

A umber f satur ds p duc usable ilk whi h ha lo g b e gath red in the Orient Am ng the re the J pa e e oak ilkw rm *A th ea yamam* G e nd the M g silkw rm *A a am n is* Helfer In N rth Ame c the best kn wn spec es of th s bfam ly Sat rn a ar th r pia *S mia e op a* L. th g lyph m s *A the ea p lyph mus* C amer th lu *Act as lun* L. the pr meth a *Hylaph a p m thea* Dr ry and the ynth a *S mi cy th* D ury

The egal m th r h ckory ho ned de l *C th nia g l* F br a d the imp ial m th *Eacle mp ial s* D y the mo t f mil members of th s bfam ly Cither a

I th ubfamily H mil n th b ck moth d rel t es the m th *Aut m* i F b us s tew thy bec t c mmo larv e l ke tho e f ome th m mb of the subf m ly r equ pped w th urt at ng (poi n u) ha s whi h n n de bl irrit t the unwary wh ha dle the c t p llar

B mby da is a m ll family of lkw rm in wh h th fr ulum s the pr ent a n *E pt* ot estig l a n *B mbyx* The f m ly c nta n the c mm r l lkworm *B mbyx m r* L. The l r a f th th ghly d me tic t d p cie feed o m lb rr le a d mbl th l rvae f sph n gid n th t they p s a m ll c udal h r Th ilk fr m th wh t yellow c c s ha bee d i e p eh t i t me The aterp ll ubject t the a ges f a d k wn p b c ed by the pr t *N ma b mbycis* N gel (ee Mi cros oridia) Th a e l att cked by tw v l d e k own s g a d fl he

The g s *E pt t a d t r l t* are oft n pl ed i ep at f m ly

S p f m ly N tu d a Thi a la g r th r f rm p fam ly f m e th 0 000 p es M t f th m m d ratel la g m th w th r d ed m ill ry p lp Tympa al ga a p e e t the m t tho x I th f w g the b e of M l e t the b f M th n t that f M

(except in the Notodontidae) and 2V and 3V do not form a basal fork

Arctiidae is a relatively large family of strikingly colored heavy bodied moths the tiger moths The larvae are generally very hairy and feed either exposed or in webs Larval hairs are incorporated into the silken cocoon The best known arctiid is probably the banded woolly bear caterpillar *Isia isabella* J E Smith There is a widespread misconception that the banding pattern of this larva predicts the severity of the coming winter

Lymantriidae (=Liparidae) are the tussock moths which are of medium size The antennae of the males are broadly pectinate The end of the female abdomen has a tuft of hairs which is deposited on top of the eggs The hairy larvae usually have prominent toothbrush tufts The most familiar species is the infamous European gypsy moth *Porthetria dispar* L which along with the destructive brown tail moth *Nygmia phaeorrhoea* Donovan was imported into New England in the last half of the nineteenth century

Notodontidae are commonly called prominents or puss moths They are distinguished from the rest of the Noctuoidea by the apparently three branched cubitus The larvae are external feeders and the pupa is formed in a cell in the ground or in a loose cocoon on the surface The Nearctic *Datana ministra* Drury (the yellow necked caterpillar) and *Schizura concinna* J E Smith (the red humped caterpillar) are pests on apples and other trees

Noctuidae (=Phalaenidae) are the owlet moths an extremely large family of mostly dull colored medium sized moths The vast majority of moths which are attracted to lights belongs to this family As exemplified by the genus *Catocala* the forewings are almost always dully and cryptically colored They cover the hindwings which may or may not be strikingly colored when the insect is at rest The larvae are mostly exposed foliage feeders but a few such as *Papaipema* are borers Some of those of the genus *Eublemma* prey on scale insects one being an important enemy of the commercially valuable lac insect Pupation is usually in the ground

The family includes many agricultural pests The cutworms *Euxoa* and *Peridroma* attack a large variety of plants as does the army worm *Leucania unipunctata* Haworth The former derive their name from the habit of cutting off shoots at the surface of the soil without consuming them the latter from the fact that they often appear in vast numbers An exceedingly important pest *Heliothis armigera* Hubner is variously known as the corn earworm cotton bollworm and tomato fruitworm Its diet may be surmised from its name

Superfamily Hesperioidea There is one rather large family the Hesperiidae The skippers are small to moderately large heavy bodied mostly diurnal insects with a clubbed antenna which is bent curved or reflexed at the tip Forelegs are fully developed and bear an epiphysis The forewing have all veins arising separately from the cell rarely there is some slight stalking The frenulum is absent except in the male of *Euschemon* The larvae have a prominent constriction or neck behind the head and often live in leaves drawn together by silk Those of the giant skipper Megathyminae are borers in yucca and agave The pupa is usually enclosed in a slight cocoon

The name skipper refers to the rapid erratic flight of most species One familiar American species is the silver spotted skipper *Epargyreus clarus* Cramer another is the sachem *Atalopedes campestris* Boisduval The Australian *Euschemon rafflesiae* MacLeay is placed in a separate subfamily largely because of the presence of a frenulum in the male In Mexico the caterpillars of the Megathyminae are fried and canned for human consumption

Superfamily Papilionoidea These butterflies are small to large diurnal insects with clubbed antennae that are rounded at the tip and not bent or reflexed The forewings always have two or more veins which are stalked The frenulum is absent The larvae have no constriction behind the head and are usually exposed feeders The pupa is naked with the exception of *Parnassius* and relatives and is often suspended by caudal hooks the cremaster Pupa are either inverted or held in an upright position by a silken girdle

Papilionidae is a family of which swallowtails and parnassians are typical common forms These are the only butterflies with fully developed forelegs bearing an epiphysis They are also unique in having the cervical sclerites joined beneath the neck The hindwings have only one well developed vannal vein except in the anomalous Mexican *Baronia brevicornis* Salvin The larvae have an eversible forked organ on the prothorax the osmeterium This organ disperses a disagreeable odor and presumably functions as a defensive mechanism *The pupa is girdled In the boreal genus Parnassius* and some other members of the family a horny pouch or sphragis is found This is secreted by the male during copulation and covers the genital opening of the impregnated female The common genera *Papilio Graphium Battus* and *Parides* (=*Atrophaneura*) all contain large and attractive species many of which possess the characteristic tails which give the family its name The bird wing butterflies *Ornithoptera* and *Troides* are among the largest and most beautiful species In North *America the eastern tiger swallowtail Papilio glaucus* L has dichromatic females one form being black and yellow striped like the male and the other being entirely dark brown or black the latter presumably mimicking the protected *Aristolochia* swallowtail *Battus philenor* L The larva of the orange dog *Papilio cresphontes* Cramer is sometimes injurious to citrus

Pieridae is a family of which common members are whites sulfurs and orange tips These butterflies are unique in lacking the prespiracular bar at the base of the abdomen The forelegs are completely developed in both sexes but lack the epiphysis The tarsal claws are bifid A great many

es exhibit triking exual dim rph m Most ha all hit y llow or orange in col r The r ep rtal t pla t of the f m lie Cruc (m tard) Leg min ae (b a s pea et) Capparidacea (capers) The p pae a us- led by a gi dle as n the Papil n dae rn pae L, the bbage b tt rfly is on f most eco mically importa t butt rfl e at ing cult ated cru ife Europe nd North The alfalf b tt rfly *Col as eurythem* dier L is maj r pest f alfalfa in Ame ica utterfl es of thi family a e ften extremely udant The gi t s lfu (*Ph eb*) and oth rs m m gr te in huge swarm Th l rvae of the u an *E h a s talis* Westw od are grega living together in a est.

Nymphal d e is family of f u fo ted b tter s Th proth ic l gs a atly atrophied in th sexes d the patag are lw ys well dev l d and h nly s le ot zed

In th bfam ly Da a nae the adults are tough d d ha e an a nd taste to h mans They a ossedly di t t ful t most p ed tors and a e mod ' in a great m ny mim ry complexe d and ly d trib ted and m g t ry m ar h r red, butterfly *Dana s pl xippus* L. is the known r present t f this sul f mily In h Am rica t i mum ked by the vic roy *menitis a h ppus* Cramer a member f the Nymph linae

Th ek fivi g lthomiin e, r gla y wi gs are rturally ery m l m th danaid Many of ab br ad tran p rent areas n the w ng m rich th scales are educed to sh rt hair

Th large, c mopol tan s bfamily Satyri ae including the woodnymph m adow b wns ingy a d ar tic is cha ct zed by the weak ing fl ght of th magi s d th bl dder l ke n gi l th b es l the et s n the fo ewings most pec es. Th larv e feed p marily on grasses. The g e *E bia* nd *Oe eis* pe et t remely bosp tabl ct a d alp ne s t at s

The bf m ly M rph na s a trop c l gr up of large butterflies lled t the atyrids Th brill ant metallic spec es of the gen *Mo ph* are mong the most be uti l in e t The well kn wn owl butterflies, certa *Caligo spe* es whose u d rs de bear con p cu eyespots, bel ng t th group

The ubf m ly Nymphal ae is xt mely la ge and worldwide ed although stru turall q te heterogeneous W known gen a of the temp te r de *A gyn* is a d *B l* (f still) d *Euphydryas* (ch kerspots) *Poly* (gl wi gs) *Nymphalis* (t rto e h lls) (thi tl butt fl es) *L m tis* (adm al) ocamp (ha kb rry b tt fl e) Th b- n r prese ted n th t p cs by num ou d pec es. Th l ng w ged genus *H l* placed in a ep rate subf m ly n of M lle a m m s and the g nu th l b tt fl es cont n pec es whos ry clos resembla t dead PROTECTIVE COLO ATION

Libytheidae is a sm all fam ly f le s than twenty p cies d vided into tw g nera *Libyth a* and *L bythe na* c lled nout butterfl e The f rel gs of th male are educ d and nonfunct n l th of the fem le are smaller than the pterothoracic legs but are used in walking The palpi are long and porrect These b tterfl es are eparated f om the nymphal ds by the st uct re of the p th ra ic leg and by featu e f the thor x but th ir affini tie are clea ly with the Nymphal da

Ly ae id e a family wh h ncludes the bl es g s me ha treaks pp rs and metal marks The butterfl es are unique in th at the l mella of the me d crimen is not compl te to the fu ca In the mal the pr tho ac c legs wh ch alwa s lack tarsal claw a e functional n ne subfam ly the Ly aeninae a d nonfun t al in the othe tw sub- famil es Riodin nae and Styg ae Th e of the fe mal a e smaller than the pte thorac c legs but are f n tio al The eyes a ema ginate at th antennal bases at lea t nt gu us w th them The p tag a a neve cl rot zed The larvae are mostly flat t ned a d th pupa is usually girdled The larv ge rally ha e a m tu li t c r lat nship with nts which tend and prot ct them in return for ho ey dew wh ch th y ec ete a few a e p eda ous

The ubfam ly Riod nin e r m tal ma k is p i ma ly Neot op al They re mall butterflies oft n b ll ntly ol red

Th subfam ly Lyc eninae wh h in ludes the blu opper hairstre k and harveste s re m nute t m d um s zed nse ts wh ch re fte a me- talli c blue or g en n th uppe urfa e Th larg t spec es th Aust al an *Liphyr b as lis* Westwood with an xp n e f bout 75 mm The at rp ll s l e n ant nests and p ey on a t larvae The h rv ters (*G rydus Spalgis* nd *F n sica*) ha e p edac u larv that f d n hom pteran such as ph ds m mb ac ds and coccid wh ch re attended by ants In th U ited States the bean

Tabl 2. Importa t i j rious Lepid pt ra

N m	D m ge by l rv
Aege d	
Pea h tree bore *Sa naidea ex tios*	Feed der ba k th most m po ta t nsect j ri us to pe h
Sq h vi bo *M l ttia ly f mis*	I fests n cucu b ts ften ry destru t
Gel h d	
A go m is gra m th *S totrog re lell*	Feed n gra t rage d th fi ld mported from E rope
Pi k bollw rm *P t nophora gossyp lla*	Feed bolls, uses f l f blossom t pe most impo t t insect nj ri t cott
Tineid	
Case-m k g l thes m th, *T nea pell lla*	Cl thes m th l rv fest wool prod ts, ph l t ry f rs, d th dried m l prod
W bb g l thes m th *T neol bis liell*	
Ca pet m th, *T icho- phaga tapet lla*	D m ge m l t th t by l thes m th but less com m

Table 2 Important Injurious Lepidoptera (cont)

Nam	D m g by l v e
Olethreutidae	
Co ll g m th *Carpoc ps p mon lla*	La va bo s t pples a d n e tl r f ts m st impo t nt p st f apples
Or ntal p l motl *Lasp yre ia mol sta*	F ed on f ts a l tw gs f p ches plum etc
Tortricidae	
Spruc l lw m *Ch isto u f nif r a*	Def l t r f a t a e s of co f ous f est
Ugly n st t t l l l r ll m t *C e* spp *T l t* spp	F l o l e a d f uits of ı pl a d othe f straw be ry sh d tr or ame tal pl nts t
Pyral dae	
O ie t l bo Chil impl	Very d str ct to r c ı A a
De m th *Gall a mello ll*	Dest y combs ı n gle ted be l v s
I l n me l th *Plod t rpun t lla*	W desp l n l ery impor t nt pest of d d fr t d m l products mport d f m E op
M d t r n n flo m th *Eph st k hn ll*	I fest flou t d g in c l
G ap l f f ld r D m a f ne li	Som t mes n mport nt d f l t f g ap e
Geometridae	
Sp g nk w m *P l l n l* f ll cank rw m *Al ph la p m t a*	D f l at fr it d sh d t ees ı tb k y ra p g c n k w m o w nt rs s p p f ll nk w rm an egg
Sph ng dae	
Tom t h r wo m *Phl geth t u q qu m l t* t l a o bo worm *P extus*	Large l r e e m t p p sts of t m to d t b c lso f l o th sol n ceous pla ts
Las ocamp dae	
T nt t p ll r *M l os n a* spp	S u d fol tors f f est h l d cl d t ees
Arctiidae	
F ll w l w m *Hyph nt i unea*	F d w l n ty of f t h l n l f t t es
Lymantri dae	
Eu pe n gypsy moth *P rth t d pa*	Impo t nt def l t of f est h l nd f t t es ı N w Englan l
Brown t l moth *Nygm a ph eo hoe*	S m l t gypsy m th
Noctu dae	
Cutwo m *E oa* pp *P idrom* pp tc	N m pe es l m g many rop pl nt
A my w rm *Le n n p tl la*	V es t m l u ly ı l d nce ı p d y ra t loca g t l m g to co l tl g es
Co e worm cotto bollw m t m t f tw rm tol cco b lw rm *H li thi a mig a*	F ee l gly mpo t nt cosmo pol t n pest H k g m y lt ated pl ts
P eridae	
C bbag l tt fl es *P* pp espec lly *P apae* ı U ted St tes	Pests f v n lt v ted cr f rs
Alf lf b tt rfly *Col a ryth m*	Impo t t pest of alf lf in so thwest rn U ted St tes

lycaenid *Strymon melinus* Hubner ha at times bee an important pest of hops

BIOLOGICAL ASPECTS OF LEPIDOPTERA

The Lepidoptera are a group of in ects on whi much biological re earch remain to be done great deal is still unknown about the genetic physiology and ecology of this group Moreove butterflies and moths have proved eful as exper mental animals in genetical re earch

Ecology and distribution The variation in larv habits is discussed under the different familie Lepidoptera of all tages are ubject to the attack of a large number of predator including bird mammals lizard frogs and piders They al must be wary of rapacious in ect such as drag r flies mantids phymatid pentatomids a ilid an vespoid Some wasps (Sphecidae) paralyze cate pillars ovipo it in them and place them in pe cially constructed cells Others (Trachonids an ichneumonids) place their eggs in the caterpillar without paralyzing them In either ca the cate pillars serve as food for the growing wa p larv in ide them Some chalcids ovipo it in the eggs o Lepidoptera

One mite *Myrmonyssus phalaenodectes* Treat in fests the tympanum of a variety of moth and an oth r *Otophetdomenis zalestes* Treat re tricted as far as is known to the genus *Zale* P eudo cor pion of the genera *Atemnus Stenonithius* and *Ipocheridium* have been found on adult of vari ous pecie Lepidoptera are al o sub ject to viral bacterial protozoan and fungal infection

The Lepidoptera penetrate almo t every corne of the globe with the major exception of Antarc tica Butterflies of the genus *Boloria* have beer taken at Alert on northern Elle mere I land about 400 miles from the North Pole Arctic and alpine tundra areas normally support a lepidopteran fauna which although relatively poor in pecie i rich in numbers After rain de ert are often ali e with butterflie and m th Tropical areas are by far the riche t in pecie One of the strange t habitats oc cupied by a lepid pteran i the hair of the ne trop ical three t ed loth wl ere the sloth moth *Brady podi ola hahneli* Spuler a pyralid pa se its entire life cycle presumably feeding on algae which gr w in tl e hair The following outline indicate some of the habitats of larval Lepid ptera

1 Plant as ciation terre trial
   a *Feeding expo e l on foliage* flowers or plant lice
   b Feeding on foliage in wel or ca e
   c Leaf and needle mining
   d Living under bark
   e Boring in stem root fruit or ee l
   f In oil fee ling on roots
   g Il ring in or fee ling on fungi m l er wort clul mo es lichen and fern
   h Living in dried plant product such as c re al flour drie l fruit relu e h rbarium peci men

I ociat on w th soc l t
a. I beeh e
b. l a t t
I t rm te e ts
Associat s th th mals
a. I to ed a m l prod t uch a w olens
f th r
b. In ha f three-t d loth feeding n algae
In pl t l ce pa to ds
Aqu t c
a. Feed n bo ing n o mining in aqu tic
plant
b. On rock f d ng m croo gani m

I temper te zones p c es a kn wn which h
mate n every tage f th lif cycle
l dmd al e o l and g graphi riat ns
n nd t k ng the Lep d pt C l r
d a ha ter m st f eque tly ffe ted
gsh p u n ge ital a nd ther st u
re fle t l ed The n mber f b d per
n a fle differ geog aph cally

Behav or and physiology M r tion i the m st
ectacul r b ha o c ng i th ord It i
ost freq e t i the butte fl Ph bi D i
both a d th s b t s l k own i the
h s Ch y d a Hug m r to v wa ms
re fr q e tly rep rt d i m y parts f the w ld
this phen m n a well the el t d m
mal toost g of d It daily e f flyw ys h ll
b p ng d of rth s p rly u d t od
Aggr gation f b tte fl at m d puddle e
frequent sight, and m ths h e been ob erved
pump g n act h ch t l s pp g w te
small f om a p ddl nd eje t g t s t m
of dr ps fi p v f om the an
I th fi ld f l p d pt n phys logy the w rk
of C M Will m a d h s s ate g wth d
t h rm n s i la ge atu ni d a d that
of D E Be k on l rv l utr t d b ha o
P vas bilalis h ld be me t o ed Al o t
wh a e th in e t gat f A T eat d oth
n f th t n of the tymp num e p ially n
e ert n th th a yet u p e theory that t
p marily a w rn g m cha m by det t
th ult son p lse f appr ch g bats

Evolution and genetics Th e i no k ow ex
act f m ly n th o de N B T d l fam ly
found b sed n E s as a f om the T s
f t l o g n lly plac d i the Lep
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fos l Lep d pt ra a m l p d pt a f m
l T ri ry but it eem l k ly that the r
cruited ll b k in the Meso e perh p fi st
g n the Ju c
The phen m a l m m cry and p t ct e re m
idesp d in the Lep d pt r
H. Blest, 19 7 dem t ted th t ey pot p t
in cert pec es l t ese pe re p ses i
some b d Th s, they n eff ti e p ot
Lep d ter h d ant g f ma y ki d f
ti g i n, espec lly f th t dy f
popula n genet J Ge ould first demonstrated
a sex limited cha cter n hi wo k on *Colias* E B
Fo d C L Rem gt and thers h e been con
t ibuti g to g netic with studie of various butte
fl es and moth
The ppearance of dark form f arious m ths
i hea ly industrial ed a d th s hea ly so ted
a eas a w despre d phen me on Th s i dus
t l m lani m i doubtl ss d to h fti g sele
ti n pre ure and is one of the best k ow exam
pl of olut n i ctio *See* ARTHROPODA EV
OLUTION ORGANIC GENETICS INSECT PHYSIOLOGY
INSECTA PROTECTIVE COLORATION SEXUAL DIMOR
PHISM [P R E]

Bibl o phy J V B owe Experim tal stud e f mim cry n some No th Ame i n b tt rflie *Ev olutio* 12 32–47 123–136 273–285 1958 C T Br es A L Melander d F M C pe ter *Clas sifi ti of I sect* 2d ed Museum C mp Zo l Bull 108 1954 P R Eh l ch The te me tal at my of the mona ch butterfly *D aus plexip p* L. *U i Kan as S B ll* 38 (pt 2) 1315–1349 1958 P R Eh l ch The mp rat mor phol gy phyl geny nd h gher cla ficat on of the b tterfl es *U v Kan s S Bull* 39 305–370 1958 E B F rd *B tte fli* 1945 E B F rd *Moths* 1955 A B Klot *Th W ld of B tterfl es and M ths* 1958

Lepidosauria

A bcl s of the R pt l a l pid au are d p d r pt le ch a t iz d by tw tempo l f nestra In the ad an d type e th r one or both temp al ar hes may be lost Th teeth we pr mit ely s b th do t (ket) d bec m a odo t (f ed to edge of jaw) o ple odo t (f ed to s de f j w) Th ert br e we e p im ti ly am ph el (con e t b th end) d b came pr coelo (ca in f ont co ex behind) The lep d sa a r g fr m L te P rm Rece t the nly l f m *Sph d n* (der Rhyn ch ephal) d m mb f the d Squam t

Order Eosuchia Th e ch a w e pr m ti l rdlik te rest l d amph b o s form w th typ al d ap d kull a d s bth c dont t eth Th gro em r l ted t thecodo t l t the d ta ar in deq ate They ar known la gely fr m S th Af c n P mi f s ls Eosu h a l ed d ng M ddl P rmian t E e t m Exampl s ar *You g a* nd *Ch mp osa us* *S* THECO DONTIA

Order Rhynchocephalia The hy cho eph li n or be k h d w e l za dl ke diap id r pt le with a od nt teeth a d mphi o lo l ae The pr maxill ry bo typ lly w s b klike Rhyn ch ephal n li ed n t r tr l hab tat except for few ma e f rms f ert affin ty They ol ed fr m E s hi n th E ly Tri s i a d fl u sh d b efly th ugh t the w ld i th T i s s Membe of th g p rvi t d y wh l t tle ch ng i the m d rn T at or *Sph n do p tat m* of New Z aland Exampl re *Hom s u us* nd *Sph odo* *S* RHYNCHOCEPHALIA

Table 2 Important Injurious Lepidoptera (cont)

N m	Dam g l y l va
Olethreutidae	
Codl g moth *C p ap pom n ll*	La bo es pples and som ther fru ts m st mpo tant pest of apples
O i tal p h motl *Laspevr a m l l*	Feed o f its an l tw gs of p ch s plum et
Tortric dae	
Spru b dwo m *Cho- i lon r f m f an*	Defol at r of v st a eas of co fe ou f est
Ugly e t to t d l f oll rs t *Ca oec* spp *T l iz* spp	F ed on l a es nd f ts of ppl nd other f ts t w be y h de t ees o n mental pla tc
Pyral dae	
O i t l r bo *Chil n ple*	Very d tr t e to r ce n As a
B m tl *G ll a m ll n ll*	Dest oys mbs n eglected beeh e
I l n me l m th *Plod a int p l ll*	W desp l nd ry por tant pest of d ed f t a d m l p oducts imported f m Eu op
M d t n flou moth *Eph l k hn lla*	Inf st flou to ed gr c e l
C p le f f ld *D m fu l s*	Som t mes n mpo t t d f l at of g j s
Geometridae	
Sp g ca k wo m *P l l r l* f ll k w m *Alsophil p m ta*	D f l t f t nd h d t ees o tb k ye rs g a k worm o w nt rs p p f ll c k rw rm a gg
Sph ngidae	
Tom to ho nw rm *Phl g th l us q q ma l l s* t l acco ho w m *P s xtus*	La g l r e most con p cu pests of t m to nd t b a l f d o th sol n eo s pl ts
Lasiocamp dae	
T t cat p ll *M l c m* pp	S r d fol ators of f t, b de n l o ch d t
Arct dae	
F ll webw m *Hyph nt ia n*	F d w d a ty f f est, sh de n l f t tr es
Lymant i dae	
E rope n gyp y m th *P th l i dispa*	Impo t t def l t f f t h l nd fru t t es N w Engl n l
B own t l motl *Nygm ph eor hoe*	S m l r to gypsy m th
Noctuidae	
C tw rms. *E ixoa* pp *P idroma* spp t	N n pec s dam g m ny rop pl nt
Arn y w m *Le un punct t*	V ies t m d u ly i l d nce i e d m y rs t does g t l m g to co n a l oth sses
Co n earw m cotto bollworm tom to f tw rm t ba co bu lw rm *H l oth s m g a*	F eed gly mpo t nt cosmo- pol t n pest tt k g m y cult ted pl ts
P eridae	
C bb g butt fl es, *Pi is* pp espec lly *P rapa* U ted St tes	Pests f v r ll ted cruc f rs
Alf lf b tt fly *Col s rvth me*	Import nt pest f lf lf i so thwest n U ted States

lycaenid *Strymon melinus* Hubner has at time been an important pest of hops

BIOLOGICAL ASPECTS OF LEPIDOPTERA

The Lepidoptera are a group of in ects on which much biological re earch remains to be done A great deal is till unknown about the genetic physiology and ecology of this group Moreover butterflies and moths have proved u eful a experi mental animals in genetical research

Ecology and distribution The variation in larval habits di cus ed under the different familie Lepidoptera of all tages are subject to the attack of a large number of predators including bird mammals lizards frogs and pider They al o must be wary of rapacious in ects such as drag flies mantids phymatids pentatomid a ilid and vespoid *Some wasps (Sphecidae) paralyze cater* pillars ovipo it in them and place them in pe cially constructed cells Others (brachonid and ichneumonids) place their eggs in the caterpillar without paralyzing them In either ca the cater pillars serve as food for the growing wasp larva in ide them Some chalcids ovipo it in the egg of Lepidoptera

One mite *Myrmonyssus phalaenodectes* Treat in fests the tympanum of a variety of moths and an other *Otopheidomenis zalestes* Treat i re tricted as far as is known to the genus *Zale* P eud cor pions of the genera *Atemnus Stenowithius* and *Apochenidium* have been found on adults of vari ous specie Lepidoptera are al o subject to viral bacterial protozoan and fungal infection

The Lepidoptera penetrate almo t every corner of the glol e with the major exception of Antarc tica Butterflies of the genus *Boloria* have been taken at Alert on northern Elle mere I land about 400 miles from the North Pole Arctic and alpine tundra areas n rmally support a lepidopteran fauna which although relatively p or in pecie is rich in numl ers After rain de erts are often alive with butterflies and moths Tropical area are l y far the riche t in specie One of the strange t hal itat oc cupied by a lepidopteran i the hair of the neotrop ical three toed sloth where the sloth m th *B adyp odicola hahneli* Spuler a pyralid pa es it entire life cycle presumal ly feeding on algae wl ich gr w in the hair The following outline indicates some of the hal itats of larval Lepidoptera

1 Plant a ociations terre trial
   - *a* Feeding exp o ed on f liage flowers or plant lice
   - *b* Feeding on foliage in web or ca e
   - *c* Leaf and needle mining
   - *d* Living under bark
   - *e* Boring in stem root fruit or ee ls
   - *f* *In oil feeding on roots*
   - *g* Boring in or feeding on fungi m es li er w rt club mo e lichen and fern
   - *h* Li ing in dried plant prod ict uch a cere al fl ur dried fruit refu e herl arium speci men

A soc at o th soc l s sect
 l beeh ■
b l ant nest
c. l term te n ts
Asoc t th other a m l
 l t ed animal prod t s h a wool ns
 f ath
b l ha f three-t ed loth feed ng on algae
c l pl t lic a pa s ito d
4q t c
e. Feed o bo g t n mm ng n aquatic
 pla t
b On rock feed ng on m croorga ms

In t mp te zo es pec e r known wh ch h
em te m e e y t ge f the l fe cy l
l di dual a l and geog ph c tatt ns
 mm and trik g in th Lepid ptera Col
 d e a ch ra te m t freq e tl affected
 t g h p enat n g tal s a d the t s
 es a e often s l ed Th n mber f b ood per
person ften d ff rs ge ■ ph call

Behav or and physiology M gr t on s the most
pectacul b h t occ rr ng i the ord It
■ t l equ nt s the b tt fl es *Pho b s D n*
Libyth a a d ther b t s l o k wn n the
m th h s *Chrys r d* H g migr t ry warm
 e l equ ntly rep rted m y part f the w ld
but th ph me o a w ll a the rel t d c m
mun l oo tt ■ f d jlt d lv f flyway hill
 pp g d s f rth poo ly u de t od

Ag reg t n f butte fl t m d p ddle are a
frequ t ht d moth h e been ob rved
p mp g a t wh h n t of pi ng w t r
 t dly f om p ddl and ej t g it s a tr am
 f d p r fl e pray from the an s

I th fi ld f l p d pt n phy l gy the w k
of C. M W ll m d h c te n g owth nd
d ff ent t n h rm es i l g tu n d nd th t
 f D E Beck l rv l utr t on and b h v o n
Py t n b lalis h uld b m t ed Al o n t
w rthy a the n t g t s f A T at nd oth
rs of th f t n f the tymp um esp lly n
■ nect w th the a yet p n th ry th t t
serves p im rily a w n g mechan m b detect
 g th ult p l es f pp o h ng b t

Evolut on and genetics Th no kn wn x
t t f m ly s tl d N B T d l fam ly
E set da ba ed *Eo s tri* f m th Tri a
of Au t l a wa g n lly pla d n th Lep
d pt a b t t po t s rv d btf l The e
 l est f l Lep d pte a m ol p d pt fr m
th ly T rt ry b t t eem l kely th t th r
d ted w ll b k th Mes z p h ps fi t
d ff nt t ng n th J

Th ph n m f m m ry d p tecti e m
bf e w d p ad the Lep d pt a

A Blest 19 7 dem t ated th t eyespot pat
t rn rt pec l t e c p respo es
■ b d Th th y r n effects pr t c
t dev

Lep d pt h d ntages f m ny k nd of
k t est g t especi lly f the tud f
population genetic J Gerould fir t dem trated
a ex limited character in hi work on *C lia* F B
Ford C. L. Remingt n and ther ha e b n c n
tributing to genetic with studi f ari us butter
fl e and m th

Tl e appearance f d k f rm of variou moth
in h ily indu trialized and thu hea ily noted
area a wide pread phenomen n This ind t
t al mela m" in d ubtles due to h fting sel
t n p ess r and i one f the best known x m
ples f e lution in action *See* ARTHROPODA Ev
OLUTIO ORGANIC GENETICS INSECT PHY IOLOGY
INSECTA PROTECTIVE COLORATION SEXUAL DIMOR
PHISM [P R F]

Bibliog phy J V Brower Exp r mental tudi s *of mimicry* i ome N th Am can b tterfl *Ev olution* 1 3 -4) 123-136 273-28 1958 C. T Br es A L. Meland a d F M Carp nter *Clas s fi t n f I ts* 2d ed Mu um Comp Zool Bull 108 1954 P R Ehrl ch The tegumental an t my f the monar h b tte fly *Dan us plexip p* L., *Un i K s s Sci Bull* 38 (pt 2) 1315–1349 1958 P R Ehrl h The c mparati e m r ph logy phyl g ny nd higher la fic t f the butt rfli *Uni Kansas Sc Bull* 39 305–370 1958 E. B F d *Butte fl s* 194 E B F rd *M ths* 19 5 A B Kl ts *Th Wo ld f Butte flies d M ths* 1958

Lepidosauria

A ub l f the R pt lia lep d a rs are d p id r pt l cha a t r zed by tw t mpor l fe estra In tl e ad c d types e the r both tempo al r hes may be lo t The teeth were primit ely ub thecod nt (in ock ts) and became a r d nt (f ed t edge of j w) o pleurod t (fu ed to de of jaw) Th rteb e were p im t ely am ph l u (on a e at b th nd) a d be ame procoel n (c n in f ont c n ex behind) The l p do a a rs ■ f om Lat Permi to Recent the ly l ■ forms e *Sphe odon* (order Rhyn h eph l a) nd memb of th rder Squam t

Order Eosuchia The s chians wer *prim ti e l za dl k* t r t l a d amph b o s f rm w th typ al d ap d k ll a d ubthecod nt te th The gr p ms r lated t the od nts but the data r mad q ate They a e kn wn l rgely from S th Afr an Perm n lo l Eo uch ans l v d d r g Middl Perm an t E c ne t me Examples *Y ung a* nd *Ch mpsos u us* *See* THECO-DO TIA

Order Rhynchocephalia The rhyn hoc ph l ans o b k b ads *we e l za dl ke d ap id* pt l s with acr dont *teeth* nd mphi oel u rtebrae The p m x llary bone typ cally w s be klike Rhyn ho phal *ans l ed i* t rrestri l habitats e cept for a few m a f rms of un e ta ffi ty Th y l ed fr m ■ hi ns i the Early Tr a i and fl h d b i fly th ughout th w rld n the Tria s M mbe s f the gro p survi e today with l t tl ch g i the mod rn Tu t a r *Sph nodon p t tum* of New Z al nd Examples are *H mo s u us* a d *Sph n d* *See* RHYNCHOCEPHALIA

Table 2 Important injurious Lepidoptera (cont)

N me	D m g i y l
Olethreutidae	
Co ll g motl *C poc ps p mo ella*	L bo ppl nd som other fru t m st impo tant pest of pples
O nt l p ch moth *Laspeyr s m l t*	Feeds n f l tw gs of p ches plum etc
Tortricidae	
Spruc bu lwo m *Cho- isto ra fum f*	Defol t f t o f o f est
Ugly t to t d l af ollers tc *Ca oec* pp *T l iz* spp	F d on l l f ts of apples nd oth f ts t w be y sh le t ees o n m nt l pl nt tc
Pyralidae	
Orient l ce bore *Chil mpl z*	Very dest u t to A
Bee m tl *C ll m ll n ll*	D t oy combs in n gl cted l h
I d an m l m th *Plod i p nel ll*	W lesp l l ery mpo tant p t of l l f t d imal p o l t mp te l f o Fu p
Med t ne n fl u motl *Fphest ku hn ll*	I f t flou t ed g l
G pe l f f l ler *D sm f al*	Som t m s an i po t t l f l t f g p
Geometridae	
Sp g c k rwo m *P l r l e n t* f ll c nk w m *Alsoph l pom t*	D f l te f t d sh l t tb k y rs sp g k rw m o w ters p p f ll k w m n egg
Sphingidae	
Tom t l w m *Phl g th t q q m c l lus* toba o h w m *P ext*	La g l r most c n sp o pest f tom to l t l cco l o f l o th sol eo pl nts
Lasiocampidae	
T nt t p ll rs *M l* m pp	S o s d f l t f f t h l l o l l tr es
Arctiidae	
F ll w bworm *Hyph t c ne*	Feed on w l ty of f est, al l d f t tr es
Lymantriidae	
Eu p gypsy m th *Po th l a d spa*	Impo ta t l f l t f f t l l l f t t ees i N w F gl d
B ow t l m th *Nyg i ph eo hoea*	S m l to gypsy m th
Noctuidae	
Cutw *F* oa pp *Pe drom* pp t	N m pec es l m g n y crop pl nt
Arn y w m *Le u p t t*	V es t m l ly t l ce p l m y rs t loes g t l m g to corn l th gr sses
Co n rwo m cott bollw m t m t fr tw m t l co b lw rm *H l this m g ra*	I eed gly mpo t t cosmo- pol t n pest tt k g m y c lt ted g l t
Pieridae	
C t bage l tt fl es, *P r s* pp espec lly *P pa i* U ted St tes	Pests f i lt ted cru f rs
Alf lf l tt fly *Col ryth m*	Impo t t pest f lf lf i so thwest U ited St tes

lycaenid *Strymon melinus* Hubner ha times been an important pe t of hops

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1 Plant a ociation terre trial
   - *a* Feeding exp e l on foliag flower or plant lice
   - *b* Fee ling on f liage in w l r ca e
   - *c* Leaf an l nee lle mining
   - *d* B ing under l ark
   - *e* B ring in tem root fruit or ee l
   - *f* In oil fee l ng root
   - *g* Boring in or f ling n fu gi mo li er w rt clul m lich a l f rn
   - *h* Li ing in dri l plant pr luct h a c re al fl ur dri l fruit refu l rl m p l men

Leprosy

A chronic infectio d e of man caused by *My obacte m leprae* (H s bacillus) and oc urring in nodul r (c taneous) and neural form This disease s believed to have originated in cen ral Afric it then pre d t all parts of Europe and subsequ ntly t the rest of the w rld After its introd tion f om the N ar Ea t the d sea e be cam demic i E rope til the si tee th ce ury the di appeared It i till widely di emi a ted the Orie t. The are n timated 3 000 000 l pers in the wo ld—about 450 in th Un ted States d o er 30 000 i Central a d South Amer a The d se is fo d in the trop c nd b- trops M l p has not y t been ult ated on b ct l gi l med ti s e c lt res r experi ental a im ls.

M l p f man d es t prod c pr g es i e infection anim l Rats h e a disea called rat l pr y char cterized by nod lar skin le ions co t ing c d fa t ba ll (*M lep mu m*) hi h is path f r ther species d can ot be e ltiv ted i v t

M l p ppe r n obl g t t tracell lar par t occ rr n large numbe s f globular cl ter (gl bi) in epithel d cell The n d lar aneo and eural ne thetic f rm of the dise se m y oft both occur in the same pat t and e th may h b t lepromatous r t berculo d leso s. I the od l form th I t tain many b illi, a d th lepr m k n t t (some what anal gou to the tuberculin skin test) is neg ative because the lepromatous tissue is not hyper sensiti e to the products of the bac llus The pa tient e entually dies as a result of complications such as amyloid sis nephritis or tul erculo i

S sceptibility to the d ease is greatest in child hood The ratio between the incidence of the dis ea e n m les and females is approximately 2 1 The incubation period va es from a f w months to many years The d ease is not highly co tag ous and p bably acquired by infecting superficial abra ons f the skin It is l kely that per on can acq ire the infection with ut de elop g manife t (clini ally recogn ed) d ea e

B cter logic diagnosis is made by find g acid f t ba lli in crap g of the na al mu s or in the t sue fluid pres ed from certa n reas of the sk Ca ation (death of t ue and tran f rma tion to a chee el k co tency) does n t occur in l pr y De vati es f diam n d phen l ulfone are the drug of ch ce in tr atment *See* BACTERIOLOGY MEDICAL HYPER ENSITIVITY MYCOBACTERIACEAE SKIN TEST [C H M]

Fi p no mol w th l p m t l p y h w g l s col eo h k o d l d b the het ight h d wh h l h ws m l atrophy d typ l f th th mb (Ph t g ph b H L A ld J)

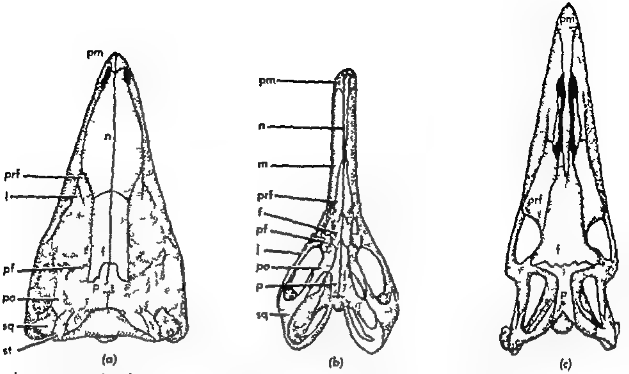
Lepton

A llecti e ame fo any fermion having a ma small r than the prot n m (a fermion a p rti cl which ob ys Ferm D rac t t ti) The e are known lept ns the electron (e^-) the μ me n (gati ely h rged mu μ^-) and th neut i ( ) pl thei tiparticle —the p itron (e^+) th μ me (positi ely charged m o μ^+) and the ant eut o ($\bar{\nu}$) Be g fe m ns, the e par t l ha e h lf dd i tegral p in fa t they all h sp ½ℏ or ½($h/2\pi$) where h is Planck s co sta t

The lepto t ract with lectr m gnetic and gravitational field by irtue of their ch rge and e gy respectively b t beyond thi they a e only known t interact thr ugh the β interactions in th ad e se These interactions ppear to co erve lept n that i j t as many l ptons c me out of an i t r t as we t in (a t leptons are cou ted gati ely of cou e) Thus e can c nside the lept n to be a single parti l wh ch n exi t in three guise *See* ELEMENTARY PARTICLE [C J G]

Leptospira

A gen f p ch t f the fam ly Spiro h tales M y pec e p duce an ac te d ea in man kn wn W l di As f r m rphol gy b l g har te t and nt gen tru ture re n rned *L ptosp* ha little i common with eith r the *T p ma* o th *Bo l a g up of sp ch t* The rga m s 4–20 μ in le gth 0 1–0 2 μ w dth a d h s el ly w u d p ls *L ptosp a* gr w w ll b ally n tifi al med a d the h ck mbry Cl fic t of p th g i p s p m r ly n n t g i *S* SPIROCHAETALES WEIL S DISEASE. [T B T]



Lepidosaurian reptiles showing dorsal view of skulls p parietal po postorbital sq squamosal f frontal pf postfrontal prf prefrontal j jugal m maxilla n nasal; pm premaxilla st supratemporal l lacrimal (a) Youngina a primitive two-arched reptile from the Upper Permian of South Africa length about 2¼ in (after R Broom D M S Watson and E C Olson) (b) Champsosaurus a Late Cretaceous and early Tertiary amphibious form length about 13½ in (after B Brown) (c) Tylosaurus a mosasaur length about 38 in (after S W Williston) (From A S Romer Vertebrate Paleontology University of Chicago 2 ed 1945)

Order Squamata *This order consists of two sub-*orders (1) the Lacertilia or lizards (including mosasaurs) which have a single upper temporal fenestra and (2) the Ophidia or snakes which *have lost both temporal arches See* SQUAMATA

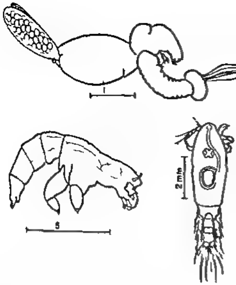
Suborder Lacertilia In the lizards the lower jaw is united at mid line the teeth are acrodont to pleurodont and the vertebrae are amphicoelous *(geckos) to procoelous Osteoderms frequently are* present in the skin The group is apparently derived from rhynchocephalians and includes modern lizards (two being poisonous *Heloderma suspectum and H horridum) and extinct marine* mosasaurs (Cretaceous) They range from Jurassic to Recent

Suborder Serpentes (Ophidia) The snakes are *elongate limbless derivatives of monitorlike liz*ards showing adaptation to burrowing swimming or brush dwelling without pectoral or pelvic girdles except for remnants of the latter in primitive forms *The lower jaw is united by a ligament the* quadrate is movable there is no parietal foramen and vertebrae are numerous and procoelous The teeth are acrodont and recurved The maxillary teeth of several groups *have grooves or enclosed* channels for poison There are arboreal terrestrial aquatic and marine forms They range from the Late Cretaceous (*Dinilysia* South America) to *Recent Included in* the suborder are boids colubrid worm snakes vipers pit vipers elapid and sea snakes [B H D]

Lepospondyli

A term used to characterize amphibian groups in which the vertebral centra basically spool shaped *are formed by ossification directly around the no*tochord in contrast to the apsidospondylous structure seen in the Labyrinthodia where the centra ossify in blocks of cartilage formed well outside *the notochord The term Lepospondyli meaning* husk vertebra has been variously used sometimes including only a restricted number of Paleozoic forms but more recently utilized as a subclass *name to include all amphibians whose vertebrae* are formed in this general fashion *See* AMPHIBIA FOSSILS

In the Paleozoic the larger amphibians were *labyrinthodonts but small lepospondyls appear* to have been very abundant as water dwellers particularly in the coal swamp these forms are commonly grouped to form three orders the Nectridia *the Aistopoda and the Microsauria* The modern orders Urodela and Apoda have a basically lepospondylous structure they are probably descended from one of the Paleozoic lepospondylous orders *(Microsauria) and hence may be included in the* Lepospondyli in a broad sense Except for the Devonian ichthyostegids the oldest known fossil amphibians are lepospondyls and the group is thought by some to have been derived independently from fish ancestors See AISTOPODA GYMNOPHIONA MICROSAURIA NECTRIDIA [A S R]



Lernaeopod d ( ) F m l S lm col thym ll (K lar) tbased R G y B d h f h w t C p p d vol. 3 R y S ty 1933) (b) M le S lm l thy (K sal) (R G y B t h f h w t C pepod l 3 R y Soc ty 1933) ( ) F -sw m g larva f P l g t (W) (C B Wils Th p p d f th W d H l g o Massach sett B ll U S N tl M m 158 509–531 1932)

Th free-swimmi g lar qui al t t the fir t copepod te t g eme ge f m the sac E te all t r mbles the hal mus l rva of Cal g d b t intern lly t s n que n h i g p f rmed fro al t be r g t at ng i th f ehead a d t m ating n a il abo e th e phagu The larva vabl f o ly h t p i d must fi d b t ap xl. t bl h t may b y o of pe h p several pec es f fi h th deg ee f h st par te pecifi ty i u lly ot p ced Adher g t ppr p i te t w th hookl ke appe dages th larv m kes und th ll t tis the led nd ev rted and bec mes embedded the ounded a the t su gen t Th t be t tempor m th d f tt hm t dege tes when th l rv m t m rph int th verm f rm F g (1l t t c)

Attachment and nutrition Pe m t att ll ment ac mpl hed n tw ways Lernaeop d d e tta hed to th w ll of th fishes gill h mb by tru gl modified sec d ma ll Th e p- pe ges a m l g t d a gel ke appe ance bec g normal egme t t The e d f ed th pex, b tto l k w ll g b ll l bened host ti l Sphyri d the head a d part f th th rax bec m embedded th with t g ll h mb r ext rn lly ft n r th d sal fin. Salm la lm par t zing lm hstand the n d om h b t f ts h t a d l t xpecta cy of l y l both famil es typ l h ts t el d h k k te ay and most bo fi hes.

Lernaeopod da appear t f ed n body fl id f the ho t They are n t c n dered a tl reat t f h popul t on e cept p ll y nder c nd ti ns f e ce i e crowd g Se COPEPODA [A F]

B bliog phy H Gurney *British Fresh water C pepod* ol 3 R S ciety monograpl 1933 C B Wil n Th e c pep d f th Wood H le re- g on M a hu ett *Bull U.S N tl M u n* 158 509-531 1932

Lespedeza

A warm ea on l g m with t f l ate lea e small pu pl pea hap d l lo oms a d e eed per p d Le pedeza al le to g w n p orer soils th n m t fo ge plant

K n le pedez n early annu al spe e s gr w exten ely f m Virg n t Ka K the c mm r striate annu l spec g wn f th as n rthern Fl r da

ll th species are ex lle t f ag a d o l serving pl t Th y re often gr wn with wheat or other m ll gra s by owing 25–30 lb of eed acre in l te w ter e ly p g After the gr h rv t d th lespedeza plants soon the oil c mpletely f a f ll i ple tiful

L p d (S I C rv t S rv)

Sericea th p n al l spedeza omewhat d ffi lt t tabl h Its ed do t germ nat d ly u l s hulled and a fied and th yo g se dl g e not s the uals It s n lly s wn alo nd th y ung g wth s u ed f g azi g hay

On sandy l t knot n m todes e e i s pe ts of m t l p d as R w o ar et f K ean le p deza i t nt to m t n matodes h w e S LEGUME FORAGES NEMATO A [P T]

Lethal dose 50

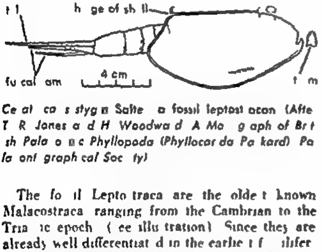
O speci l f rm f the effe t do m d an ff ct e d Th l th l d so r med n l th l d is l o wr tte a LD It is s d wh th p se that i b g n e t g ted th d th f th me tal m l Th med l thal d e i th f e the d wh ch f tal t 50% f the test m l

The LD_{50} f r t h g l t e ly to r bbt i 0 5 m ll m p k log m of b dy w ght Th d pt h w th t p fy g the LD_5 tt ti h bee to th pe ie f m l th te f j t d the we ght f th m l ed F th t sub t es a d f f t t f p cifi ti s m ght be imp rt nt

Leptostraca

A small and unimportant group of Crustacea formerly ranked with the Branchiopoda but now regarded as the most primitive of the Malacostraca. Only a few genera, like *Nebalia*, have survived to the present time, but numerous apparently related Paleozoic fossils are known.

The Leptostraca differ from the rest of the higher Crustacea, the Eumalacostraca, chiefly in having an additional abdominal somite which never bears appendages, a telson bearing two movably articulated prongs, the furcal rami, and an adductor muscle connecting the two halves of the shell or carapace. These are doubtless primitive features and indicate that the Leptostraca diverged from the main Malacostracan stock before the emergence of the typical caridoid form. The lamellar thoracic limbs are highly specialized, not primitive. The alliance of the group with the other Malacostraca is amply justified by the agreement in number of the appendages, by the sharp distinction between the thoracic and abdominal series, and by the position of the genital openings. They are most closely related to the Mysidacea, especially in their mode of development. Mysids like *Hemimysis* are now known to have an embryonic caudal furca which is shed at the first molt, and a seventh abdominal somite which later fuses more or less completely with the sixth one.



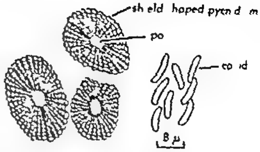
Ceratiocaris stygius Salter, a fossil leptostracan. (After T. R. Jones and H. Woodward, A Monograph of British Palaeozoic Phyllopoda (Phyllocarida Packard), Palaeontographical Society)

The fossil Leptostraca are the oldest known Malacostraca, ranging from the Cambrian to the Triassic epoch (see illustration). Since they are already well differentiated in the earliest fossiliferous rocks, they shed no light on the possible origin of the Malacostraca. See MALACOSTRACA; NEBALIACEA; PHYLLOCARIDA. [I.G.C.]

Bibliography. T. R. Jones and H. Woodward, *A Monograph of the British Palaeozoic Phyllopoda (Phyllocarida Packard)*, 1888–1889; V. Van Straelen and G. Schmitz, *Crustacea Phyllocarida (= Archaeostraca)*, Fossilium Catalogus, part 64, 1934.

Leptostromataceae

A family of fungi of the order Sphaeropsidales. Although most species are saprophytes, some are fruit tree pathogens. Pycnidia, the fruit bodies containing conidia, are black, shield-shaped, circular or oblong, and slightly asymmetrical; the opening of the pycnidium is long and slitlike. There are



Pycnidia and conidia of *Leptothyrium* ... spore.

80 genera and 345 species recognized. Many of these are conidial stages of Hemisphaeriales (order Ascomycetes).

The important genera of the Hyalosporae, whose spores are 1-celled and bright (hyaline), are as follows.

Leptothyrium, with approximately 100 species. The pycnidium is typically shieldlike. *L. pomi* causes apple fly speck.

Leptostroma, with oblong and thin pycnidia. *L. pinastri* is a stage of *Lophodermium pinastri* (Ascomycetes).

Melasmia, with pycnidia lying in a flattened stroma. *Melasmia* species are imperfect stages of Rhytisma (Ascomycetes).

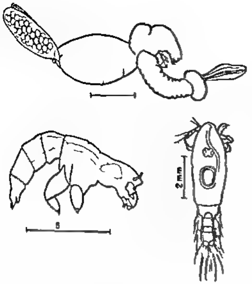
A representative genus of the Hyalodidymae (spores 2-celled and hyaline) is *Gloeodes*. It is similar to *Leptothyrium*, but the pycnidia of *Gloeodes* are gelatinous. *G. pomigena* causes sooty blotch of apple. See FUNGI IMPERFECTI; PLANT DISEASE; SPHAEROPSIDALES. [N.F.B.]

Lernaeopodoida

A group of Crustaceans known as the fish maggots, which are ectoparasites partially buried in the flesh of marine and fresh-water fish. They are characterized by (1) a modified postembryonic development reduced to two or three recognizable stages, (2) a unique free-swimming larva, and (3) failure when sexually mature to show signs of external physical maturity typical of other copepods. The female, lacking distinct segmentation and functional thoracic appendages, appears in fish as comparatively large, wormlike, sometimes tufted ingrowths. Males (illustration b) are dwarfed and, though more distinctly segmented, do not exceed female morphological development. Using modified head appendages, they cling to the female (illustration a) but retain some freedom of movement.

As a consequence of R. Gurney's discussion of Lernaeopodoida in 1933 and C. B. Wilson's account of the free-swimming stage of Sphyriidae in 1917, the Lernaeopodoida are limited in this account to the families Lernaeopodidae and Sphyriidae. Characteristic distinguishing these families are associated with the frontal filament and special structure for permanent attachment to the host.

Life cycle. The usual lernaeopodid life cycle begins with the egg, and progressing through embryonic and nauplius development which is passed in the elongated external ovisacs of the female



lern opod d ( ) F m l S lm col thym ll (K ler) (based R G y B t h f h w t C p p d vol 3 R y S ty 1933) (b) M l S lm l thy ll (K l) (ft R y B t h f h w t C pepod l 3 R y S ty 1933) ( ) F w m g larva of P l g f (W l) (ft C B Wl Th p p d f th W d H l g Massach sett B ll U.S N tl M m 158 509–531 1932)

Th fr mmi g larv qui al nt t th fi t c pepodite t g me ges f m th visac Exte nall t e mbl the hal mus l rv of Cal go da b t int rnally it un q n h a p f rm d fr taft be at ng i th f eh d a d t m n ti g i l bo th e ph gu The larva n st f only ho t p od mu t fi d h t rap idl A it bl ho t m y b y of pe h p ter l pec es f fi h th deg ee f h st p r te specifi ty s u lly n t p n ced Adhe ng t a pp pr at t w th h kl ke app dag th larv mak a w d n th host tis th o led tube i everted nd bec me embedded n the w ded e th t eg t s Th t be a t mpor ry m th d f ttachm t dege tes b n th l rv m t m ph es i t th erm f rm stag (ll t at)

Attachment and nutrition P rma ent att h ment is mpl h d tw ways Ler aeop d d e tt hed t th w ll f the fi hes g ll h mb b str ngl mod fied ec d ma ll Th e ap pend ges m a el g t d a g l ke ppear e bec g orm l s gm ntat n The e d f e d th pex b tt l ke w ll g b ll l es bu ed i h t t e In Sphyr d the he d d p rt f th th b m mbedded the withi th g ll hamb r tern lly ft ea th d al fin. *Salm ncol s lm* p t g lm rh t nd th d m hab t f it h t d fa a l f pect y f l y l b th fa l es typ l h t l d sh k kat y ad most bony fishe

Lernae p do da app ar t feed n b dy fl ids f th ho t They re n t e n d ed a threat to f h p pulat ons e ept p lly u de co d ti n of e e i e rowd Se COPEPODA [A F]

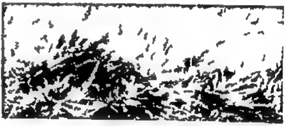
B bl ogr phy H Gurney *Brit h Fresh ater C p poda* 1 3 Ray Society m n r aph 1933 C. B Wil n The c p p ds f the Wood H le re g M s hu ett *Bull U.S N tl M seum* 1 8 509–531 193

Lespedeza

A warm ea on l m with t ifol ate lea e mall ple pea hap d blo om d e eed per pod Lespedeza a af le to g w poorer ils th n n o t f age plant

K e n le pede a a early annual pe is g w exte ely fr m Vi gi a t Kan K b the c mm r str ate ann l spec s g wn as fa th as northern Fl r d

B th species a e excelle t f nd il serving pl t Th y fte gr wn with wh at r oth m ll gra s by owing 25–30 lb of eed acre in late wi ter ly p i g After the g n h rv t d th l p d a pla ts oo r th soil completely f nf ll plentiful



L p d (S l C rvat S rv)

S ce the pe e nial le pedez omewh t d ffi ll t establi h It eeds do n t germ nat d ly unle h lled nd sca fi d and the you g dlings a ot s igorou the uals It i ally wn l d th y ung g wth s u d f grazi g hay

O a dy soil r t k ot n m todes are eri p t f m st le p d s R w n iety f K l sped e i t t to m st ematode howe e S LEGU IE FORAGES NE ATODA [P T]

Lethal dose 50

O e pe l form f the ll ti e do or med n eff t e d e The lethal d 50 or med n l th l d e l wr tt LD It is ed whe th r p that is b g i e t gated th de th f the e p ime tal mal Th med n l th l d the f e th d wh h i f tal to 50% of the test an m l

The LD f r t y h n s be t ou ly t bbit i 0 5 m ll am pe kil g m f b dy ght Th d pt h w th t pe fy g the LD t h bee g n t th pe e f n m l th r ute f nje t d th we ght f th m l ed F ther t x s b t n e a d f f t t f p c fi t n m ght be import t

The use of the concept of LD_{50} is not restricted to toxicology because there are many therapeutic substances such as digitalis which can be assayed more conveniently by their lethal effect than by their therapeutic effect. The same active principle is involved in both effects. See BIOASSAY; EFFECTIVE DOSE 50; TOXICOLOGY. [C.W.H.]

Lethal gene

A gene which brings about the death of the organism which carries it, either when homozygous (that is, a recessive lethal) or when heterozygous (that is, a dominant lethal). Lethal genes constitute a very common class of gene changes and are a reflection of the fact that genes control the processes essential to growth and development of organisms. Dominant lethal genes are rapidly eliminated, but the recessives are retained with considerable frequency in natural populations of cross-fertilizing organisms.

Many lethal mutations have proved to be losses of small or large sections of chromosomal material rather than gene changes in the strictest sense. When lethal mutations or losses occur, the effect is expressed as a failure of growth or as an abnormal course of development leading to the death of the organism carrying them. Most detectable lethal genes are recessive and are expressed only when homozygous. If the processes controlled by a particular gene come early in the developmental sequence, the disturbance produced by its loss or mutation is often severe and extensive; if the processes occur later in the sequence, the disturbance usually has fewer ramifications. An analysis of the effects of lethal genes provides a valuable means of investigating the complex processes of embryological and later development, and in the case of man has practical medical implications as well. In microorganisms the study of lethal biochemical mutants has opened a new era in the unravelling of biosynthetic processes.

The following are examples of lethal mutants: biochemical lethals in the microorganisms *Neurospora* and *Escherichia*; lethal chlorophyll mutants of higher plants; Notch and many others in the fruit fly *Drosophila*; Creeper in fowl; Yellow, Brachyury, *W* anemia in the mouse; gray lethal in the rat; Dexter in cattle; thalassemia, sickle-cell anemia, and many others in man. See GENE ACTION; HUMAN GENETICS. [D.F.P.]

Bibliography: E. Hadorn, *Letalfaktoren in ihrer Bedeutung fur Erbpathologie und Genphysiologie der Entwicklung*, 1955.

Lettuce

A cool-season annual (*Lactuca sativa*) of Asian origin and belonging to the plant order Campanulales. Lettuce is grown for its succulent leaves. Four subspecies of this leading salad crop which are grown are head lettuce (*L. sativa* var. *capitata*), leaf or curled lettuce (*L. sativa* var. *crispa*), cos or romaine lettuce (*L. sativa* var. *longifolia*), and stem or asparagus lettuce (*L. sativa* var. *asparagina*). There are two types of head lettuce, butterhead and crisphead or iceberg.

Propagation. The outdoor crop is propagated by seed usually planted directly in the field, but also occasionally planted in greenhouses for later transplanting. Field spacing varies; plants are commonly grown 10–16 in. apart in 14–20-in. rows. Greenhouse lettuce, predominantly leaf and butterhead varieties, is transplanted to ground beds with plants placed 7–12 in. apart.

Uniformly cool weather promotes maximum yield of high-quality lettuce; 55–65°F is optimum. Heading varieties are particularly sensitive to adverse environment. High temperatures prevent heading, encourage seedstalk development, and result in bitter flavor and tipburned leaves. However, varieties vary considerably in their resistance to these high-temperature effects and to diseases. Commercial production of lettuce is extensive in several California and Arizona valleys where mild winter and cool summer climates prevail.

Crisphead or iceberg lettuce is the most widely grown type; strains of the Great Lakes and Imperial varieties account for most of the acreage. Popular varieties of other types of head lettuce are butterhead, Bibb, and White Boston. Grand Rapids, cos or romaine, and White Paris are popular types of leaf lettuce.

Harvesting. The harvesting of heading varieties begins when the heads have become firm enough to satisfy market demands, usually 60–80 days after planting. Most western-grown lettuce is field-packed in paperboard cartons and chilled by vacuum cooling.

Leaf lettuce and cos lettuce are harvested when full-sized but before the development of seedstalks or a bitter taste. This varies from 40–80 days after planting.

California raises more lettuce than any other state; Arizona and Texas are next in importance. Total annual farm value in the United States is approximately $123,000,000. See CAMPANULALES; VEGETABLE GROWING. [H.J.C.]

Diseases of lettuce. Lettuce diseases of greatest importance are caused by fungi and bacteria which disrupt the structure and function of the invaded parts, causing malformation, discoloration, and breakdown of tissues. The injuries produced are usually classified as spots, rots, scab, wilt, or blight.

The most serious fungus diseases and their causal organisms are sclerotinia rot (*Sclerotinia sclerotiorum*), gray mold rot (*Botrytis cinerea*), downy mildew (*Bremia lactucae*), anthracnose (*Marssonina panattoniana*), and bottom rot (*Pellicularia filamentosa*). Several fungi of minor importance cause leaf spot.

The most serious of the bacteria parasitic on lettuce are *Erwinia carotovora* and *Pseudomonas marginalis*, both of which cause soft rot. Soft rots are especially damaging when they follow injuries and diseases such as spotted wilt and tipburn.

( )

(b)

Phot ( ) H d (b) L f (F m L H Ba l y d Th n d rd Cy l pedia f H rt ltu l 2 M m lla 937)

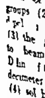
Virus d se es f l tt ce u ually are transmit ed by inse ts th t feed on the plants Big ein n ever s believed to be cau ed by a soil borne virus. Othe ir d ea es f mporta ce are mosaic, y ll and potted wilt

Tp burn, phy log cal di e e i e peci lly damaging to h d l ttu e The exa t cau e of tl s trouble is n t known *See* PLANT DI EASE PLANT PHYS LOGY PLANT VIRUS [C B R]

Leucettida

An d f the s bcl Cal nea in the clas Calcar a. These n ge ha e either a r d ate arra ment of the fl gellated chamber leu co d tru t re A d tinct dermal membrane o cortex i p ese t The sp ng c l is not li d with ch anocyt Th ell re re t ict d to the flagel la ed chamb s T fam l s the Leuca c dae a d Leu ft d e ec gn zed *Leuc scus Leuc tt* and *L al* n re ampl s *See* CALCINEA s e als CALCAREA [W D H]

Leucine

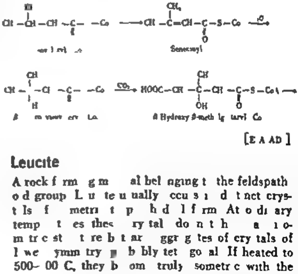


Physical constants f the omer 25 C
K (COOH 36 pk (H) 9 60
Isoelectr point 5.98
Optical rotation [ ] (H O) [ ] (HCl) +1
Solubility (00 H O)

A amin d id ed es ent al fo norm l growth of anim l Th mino acid are ch act ized ph lly by th foll w g (1) the pK the d soc t n o t nt f the i us t trat M groups (2) th soelect c p t, pH at whi h a d pol i doe not migr te i a lect ic field (3) the pt cal r t t n, or the rotati n imp ted to beam f plane-p l ized l ght (f eq e tly th D lin f the od m spe trum) p ng th o gh 1 decimeter f a sol t n f 100 gr m in 100 ml (4) sol b ty *Se* EQUILIBRIUM IONIC I OELEC TR C POI T OPTICAL ACTIVITY SPECTROPHOTOMET IC AN LYSIS.

In l uci bi synthe is carboxyl and s m c r bon at m of le a e d ed from acetat the rest of the molecul is furn hed by α ketoisovale te wh ch ari es in the biosynth is of aline A con densation of ac tyl enzyme A (acetyl CoA) with α ket so lerat followed by m of react ons an log us to th tri bo yl c acid cycle has been prop d (b t n t demonstr ted) to expl n the f rm t on of α ket oc p ic acid Th compo nd n known to y ld leucine by tr n aminat on (*se* AMINO ACIDS TRANSAMINATION)

Du ing metab lic deg adati the first steps are deamination and idati deca boxyl t on form ing i v lerylcoenzym A (iso aleryl CoA) The foll wi g seque e t kes pl c

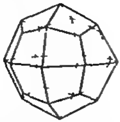


[E A AD]

Leucite

A rock f rm g m al bel nging t the feldspath o d group L u te u ually ccu s i d t nct crys t ls f metri t p h d l f rm At o di ary temp t es thes ry tal do n t h a i o m tr c st t re b t ar ggr g tes of cry tals of l we ymm try p b bly tet go al If heated to 500– 00 C, they b om truly sometr c with the tru t r conforming t th m rph logy Th com p s ti n KAlS O b t me d um may sub ti t t f p t ss m Th h d es 5.5–6 on M h sc l and the sp fi g av ty i 2 45–2 50 The c l whit nd th lu ter t eo t dull *See* FELDSPATHO D

Le t c u ly in gn u r cks that are low n il u u lly n Re nt l flows The embedd d crystals may c t n cl si ns of mag



Leucite showing trapezohedral hab t of crystal (From C S H lbut Jr ed Da a s Manual of M neralogy 16th ed W ley 1952)

netite and other minerals arranged radially or in a concentric manner Its most noted occurrence is in the rocks of central Italy particularly as pheno crysts in the lavas of Vesuvius In the United States it is found in the Leucite Hills Wyoming and in the Highwood and Bear Paw Mountains Montana I seudoleucite a mixture of nepheline analcime and orthoclase is found in pseudomorphs after leucite *See* LEUCITE ROCK PHENOCRYST

[C S HU]

Leucite rock

Igenous rocks rich in leucite but lacking or poor in alkali feldspar Tho e types with essential alkali feldspar are cla ed as phonolites feldspathoidal syenite and feldspathoidal monzonite The group includes an extremely wide assortment both chem ically and mineralogically

The rocks are generally dark colored and apha nitic (not visibly crystalline) types of volcanic ori gin They consist principally of pyroxene and leu cite and may or may not contain calcic plagioclase or olivine Types with plagiocla e in exce s of 10% are called leucite ba anite (if oli ine is pre ent) and leucite tephrite (if olivine is absent) Types with 10% or less plagiocla e are called leucitite (if olivine is ab ent) and oli ine leucitite or leu cite basalt (if olivine is present)

The texture is usually porphyritic with large crystals (*phenocry ts*) of augite and leucite in a very fine grained or partly gla sy matrix If plagio cla e occurs as phenocry t it is generally lal ra dorite or bytownite and i lightly more calcic than that of the rock matrix It may be zoned with m re calcic core urrounded by more sodic margin I eucite appear in two generati ns As large phe nocry ts it forms slightly rounded to octagonal haped grains with abundant tiny inclu ion of gla or other minerals zonally arranged Small round grain of leucite with tiny gla inclu ion al o occur in the rock matrix Augite or diop ide (ometimes rimmed with aegirine augite) and aegirine augite form the mafic phenocry t Pyrox ene of the matrix i commonly oda rich Oli ine may occur a well formed phenocry t Other min erals pre ent may include nepheline odalite bi tite hornl lende and melilite Acce ori incl id sphene magnetite ilmenite apatite and perov kite

Leucite rocks are rare They occur principally as lava flows and mall intru i es (dike an l l canic plugs) Well known are the leucite ro the Roman province in Italy and the ea t c African province In the Italian area the feld oidal lavas are e entially leucite ba alt an have developed by differentiation of ba alt m (rock melt) In the African province the le rocks are as ociated with ultramafic (perid rocks and may have been derived from peric material Thi may have been accompli hed l abstraction of early formed cry tal from a pe tic magma or by the mobilization of perid titic by emanations from depth A imilati n of stone by ba altic magma may help to decrea silica content and promote the formation of le in tead of potash feldspar The cry tallizati leucite however is in large part a functi n of perature and water content of the magma C tions of formation therefore may trongly ence the formation of leucitic rock *See* IGN ROCKS NEPHELINE SYENITE PETROGRAPHIC I INCE PHONOLITE

[C A

Leucosolenida

An order of the subcla s Calcaronea in the Calcarea The e sponges have an a conoid s ture A true dermal meml rane or cortex d e develop in this order and the pongocoel i l with choanocytes One family the Leuco oleni is recognized *Leucosolenia* and *Ascyssa* are e ples of this order *See* CALCAREA *see also* CARONEA

[W D

Leukemia

A disea e of mammals characterized by a ma increa e in the number of white cell (leuk cy in the circulating blood An increa ed numl e circulating white cells (leukocytosis) i found many di ea e proce e e pecially infecti n in the e the increa e ul ide when the underly disease proce s sub ide and repre ent a reac of the l ody t the infection pro e In leuker on the other hand the leuk cyt is per i t progre e independently of any ol vi u cau e the conditi n i eventually fatal D ring tl e c of the di ea e the white cell are di tril through ut the l ody and eventually infiltrate m organ

Normal white cell are pr duced in the l marrow of tl e healthy in li i lual a are th cell (erythrocyt) of tl e irculating l l l In leukemic patient the l ne marr w i the chief of pr ducti n of tl numer i irculating wh cell Leuk mia may n ni ntly l e regar led a form of canc r of tl e l n marr w in l ing t l ukocyte pr lucing ti u An anal g i di s in l ing tl e red c ll pr l i ing ti i f tl m row i kn wn a pol yil mia era In th i n ti n there i ac l rat l pr li ti f r l ll c ll marke lly i cr a ing tl r n ml r in tl r c lating l l l (Fig l) S HEMATO II I

Classification Th le ik mi ar i ally la fied ac ordi g t tw f t r On tl f i f lir ti n f th lln fr m n t t d atl l k m

Fig. 1 N rm l to ed bl od m h w g g ocyte ly phocyte m ocyt d cl mp of pl t l t

m y be c t w th a total co se of less th a year r hr ni la ting more than a y ar Acute and chr n l ukem a may lso be cla s fied ac co d g t th type of ell l ed In g anulocyt c (also alled m eloge us) le kemia (Fig 2a) the p ed m ting cell e embles the gr nulocyte r pol m ph lear l ukocyt f the n rmal blood S arly lymphocytic (o lymphat c) leukem a (Fig 2b) h ra t rized by a cell corresp d g to th n rm l lymphocyte and th les common monocyti l kem (F g 2c) by ll rresp d ng to th m ocyte The diff nt leukemias vary th n d ces d l nical m nifestations

Dur g th c r e f devel pme t f whit ell in th bon ma r w the app ara f the cell hanges. Th yo ngest fo m f a h var ety of hit cell esemble the p im rd l t m cell wh ch by conti mit t d i n ll me the p r nt f all blood c ll As th ell mat e i th m w L y gr d lly tak n the pp nc f the ma tur e l t g ells and fi lly e r l d nto the blood. Cha a t tic lly c t le kem a (Fig. 2d) th i l ed cell f l t mat e d are leased i t th blood at an early t ge f the d l pm t Th th ll fo d i th ul ting blood are morpholog ally immat re In chr nic leuk mia mo t of the ell reach a c ideral le degree f maturity b f re they ar rel ed al ll ugh ome y ing f rm are always present In tudy g a g n c of l kem it is p ible to pred t whether it w ll f ll w an acute r a ch nic co rse by aluat g the degree of mat rity f the cells in tl e ci c l ting blood

G locyt c leukemia in ol es th granul cytes or p lym rphonucle r ell wl ich a the cell tl at by their capacity t inge t nd destr y l ct m are o imp rtant in the defe e of the l dy again t inf ction Lymphocyte which ar in ol ed in the ther common f m of leuk mia h n a poo ly unde t od fu t on N m lly m t of them re n t f rmed n the m rrow but i mall o ga catte ed through t the body known lymph n des Howe they are n rmally pre ent n mar w and i lymphocytic leukem a th marrow m o e r with them n all t g s of devel pme t The uncomm n monocyt c l ukemia inv l es th monocyt a motile ph gocytic cell that i clo el related or ide t al to the m rophage r wander ing ll found in ll ti ue of tl e body M cyt leukemia lly follows a acute r subac t c u

A g up f di ea es cl ly r l ted t th l u k mi are the lymph mas The e are a neoplast c inv l eme t f the cells f the lymph n d d ften of the m rr w without relea e of the pro life t g cells i t the l t g blood The tum r ppe to remain l calized for a co s d ll period f t me b t t ally l es many g f the body Some f rm f lymph ma diff f m h lymphy ytic leukemia only n the bsence of the h te tic e ll f m the periph ral blood In fact i l e of lymph ma will ll ge to d nary lymphatic leuk mia b el g t ell i to the blood Neopl stic p o life t n f th gr locyti ell f the m rrow with t l m t f the ul t ng bl od e rare The e m t m d g ated by the p a doxic l te m l k m l kem They ften represent h t ph (d na y l kem and usu lly foll w th s m c e Se BLOOD

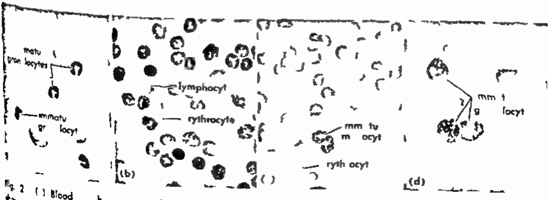
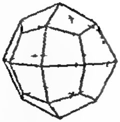


Fig. 2 ( ) Blood h g locyt l k m ( ) Bl d m cyt l k m h w g th mm showing y m d s m mm t g l t m cyt (d) Blood t g l cyt l k cytes. b) Blood h lymph cyt c l k m how m how g f ry mm t ll ng ony d som mm t lymph cyt



Leucite showing trapezohedral habit of crystal. (From C. S. Hurlbut, Jr., ed., Dana's Manual of Mineralogy, 16th ed., Wiley, 1952)

netite and other minerals arranged radially or in a concentric manner. Its most noted occurrence is in the rocks of central Italy, particularly as phenocrysts in the lavas of Vesuvius. In the United States it is found in the Leucite Hills, Wyoming, and in the Highwood and Bear Paw Mountains, Montana. Pseudoleucite, a mixture of nepheline, analcime, and orthoclase, is found in pseudomorphs after leucite. See LEUCITE ROCK; PHENOCRYST.

[C. S. HU.]

Leucite rock

Igneous rocks rich in leucite but lacking or poor in alkali feldspar. Those types with essential alkali feldspar are classified as phonolites, feldspathoidal syenite, and feldspathoidal monzonite. The group includes an extremely wide assortment both chemically and mineralogically.

The rocks are generally dark colored and aphanitic (not visibly crystalline) types of volcanic origin. They consist principally of pyroxene and leucite and may or may not contain calcic plagioclase or olivine. Types with plagioclase in excess of 10% are called leucite basanite (if olivine is present) and leucite tephrite (if olivine is absent). Types with 10% or less plagioclase are called leucitite (if olivine is absent) and olivine leucitite or leucite basalt (if olivine is present).

The texture is usually porphyritic with large crystals (phenocrysts) of augite and leucite in a very fine grained or partly glassy matrix. If plagioclase occurs as phenocrysts, it is generally labradorite or bytownite and is slightly more calcic than that of the rock matrix. It may be zoned with more calcic core surrounded by more sodic margins. Leucite appears in two generations. As large phenocrysts it forms slightly rounded to octagonal shaped grains with abundant tiny inclusions of glass or other minerals zonally arranged. Small round grains of leucite with tiny glass inclusions also occur in the rock matrix. Augite or diopside (sometimes rimmed with aegirine-augite) and aegirine-augite form the mafic phenocrysts. Pyroxene of the matrix is commonly soda-rich. Olivine may occur as well-formed phenocrysts. Other minerals present may include nepheline, sodalite, biotite, hornblende, and melilite. Accessories include sphene, magnetite, ilmenite, apatite, and perovskite.

Leucite rocks are rare. They occur principally as lava flows and small intrusives (dikes and volcanic plugs). Well known are the leucite rocks of the Roman province in Italy and the east-central African province. In the Italian area the feldspathoidal lavas are essentially leucite basalt and may have developed by differentiation of basalt magma (rock melt). In the African province the leucite rocks are associated with ultramafic (peridotitic) rocks and may have been derived from peridotitic material. This may have been accomplished by abstraction of early formed crystals from a peridotitic magma or by the mobilization of peridotitic rock by emanations from depth. Assimilation of limestone by basaltic magma may help to decrease the silica content and promote the formation of leucite instead of potash feldspar. The crystallization of leucite, however, is in large part a function of temperature and water content of the magma. Conditions of formation therefore may strongly influence the formation of leucitic rock. See IGNEOUS ROCKS; NEPHELINE SYENITE; PETROGRAPHIC PROVINCE; PHONOLITE.

[C.A.C.]

Leucosolenida

An order of the subclass Calcaronea in the class Calcarea. These sponges have an asconoid structure. A true dermal membrane or cortex does not develop in this order, and the spongocoel is lined with choanocytes. One family, the Leucosoleniidae, is recognized. *Leucosolenia* and *Ascyssa* are examples of this order. See CALCAREA; see also CALCARONEA.

[W.D.H.]

Leukemia

A disease of mammals characterized by a marked increase in the number of white cells (leukocytes) in the circulating blood. An increased number of circulating white cells (leukocytosis) is found in many diseases, especially infections. In these the increase results from the underlying disease process and represents a reaction of the body to the infectious process. In leukemia, on the other hand, the leukocytosis persists and progresses independently of any obvious cause and is eventually fatal. During the course of the disease, the white cells are distributed throughout the body and eventually infiltrate many organs.

Normal white cells are produced in the bone marrow of the healthy individual and are the ... cells (erythrocytes) of the circulating blood. In the leukemic patient the bone marrow ... products of the ... circulating white cells. Leukemia may ... form of cancer of the ... leukocyte-producing ... lymph nodes ... known as ... In this ... the ... cells markedly increase their number in the circulating blood (Fig. 1). See HEMATOPOIESIS.

Classification. The leukemias are ... classified ... Originally ... the ... leukemia ...

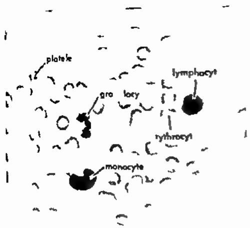


Fig. 1 N rm l to ed blood m h w g g locyte ly phocyte m cyt d cl mp f pl t l t

ma be ac te, w th a total cour e of l than a year chr lasti g m e th a yea Acut and chr n l k m m y al o be l fied ac ro ding t th type f ell n ol ed In g a ul cyt c (lso alled myel ge) l k m (Fig 2a) th p d ting cell resembles the g a ulocyte or polym rph cl le kocyte of the norm l blood imilarly lymph yti (or lymph t) l kemia (F g 2b) h racter ed by ll c p d g to th n rm l lymphocyte a d the le s comm n monocyti l k m a (F g 2c) by a cell corr pond ng to th m ocyte Th d ffe ent le kem ry their n d es d lin l ma fest t s

During th cou se f dev lopm t of wh te cell th bon m rr w th ppe nce of th ll changes The y gest f rms f ea h etv f white ell esemble the p mord al t m ell wh ch by co t u mitot c d n b m the pare t f all blood c ll As th c lls m tur n the marr w they grad lly t ke th app r e f th m tu l t c lls a d finally a e ele ed t th bl od Ch acter tic lly n a te l k m (F g 2d) th l ed ell fail t m t d le sed nt th bl od at a a ly stag f the r d l pme t Thu th ll f d n the c r l t g blood are morpl logic lly immatu e In hron c leuk mia mo t f the cells r a h a on deral le degree of matu ity bef re th y are relea ed al though me y ung f rms a alw y p t In study g a g n ca f le k mia it p ble t pred t whether it w ll foll w an acute or a hronic c r e by e alu t g the d gree f maturity of the cells n the ci culating bl d

Gra ulocyt c leukemia invol e the g an locyte lym rph nucle ells wh l are the cell th t by their apacity t ingest nd destr y bacteria a e so important i the def of the body aga n t i fection Lymphocyte wl ich a e i l ed in the other mmon f m of leukem ha a poorly und t od funct on Normally mo t f them are n t formed n the ma r w b t in m ll rgan scatte ed thr ugh ut th body kn w a lymph n des Howe r they are n rm lly pr ent in mar row and i lymph cyt c le kemia the m w i o err with them n all stages f devel pm nt The unc mm monocyt c le kemia in ol the m ocyte a motile ph g cyti cell that is cl ely related d nt al to the m c oph r w d r i g ll found in ll t es f th body Monocytic leukemi lly follows an acute or ubacute r e

A up f d ea es closely related to the l kemi a e the lymph m Th are a ne pl stic l m t f the cells of the lymph nodes a d often of the m r w w tho t r lea e f th pro l fe t ng cells int the c culating blood The t m ppe t rem i localized f r c n ider able period f t me but e tu lly ol es m ny g f the body Some forms of lymph m differ f m h lymphy yti l kem only the ab e ce f the h t t ells f om th pe iph eral blood In fact n occa al ca f lymph ma w ll h ng to o di ary l mphat leukem by el ng ts ll int th bl od Ne pl t c pro l f t f th g an l yt cells of the ma ow w th t l em t f th i culat ng blo d ar ar Th y e m t mes de g ated by the par d c l term le kemic le kem " They often rep e ent but pha e f di a y le kemia and lly f ll w the me cours *See* BLOOD

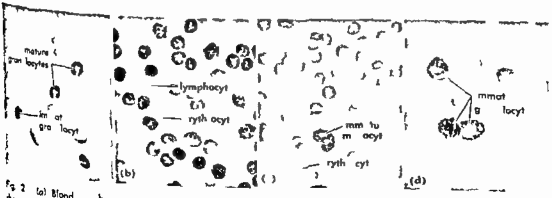


Fig 2 (a) Blood h show g y t g l cyt l k m ( ) Bl d m cyt l k m how g th mma cytes b Blood h d m mm t g f t m cyt (d) Bl d t g l cyt l k ing many atu lymph cyt l k m h w m h w g l ry mm t ll d som mm t lymph cyt

Incidence and epidemiology Leukemia has been observed repeatedly in a number of species of domestic animals notably in horses cattle and dogs Occasional cases have been reported in swine cats goats and rabbits as well as in a few wild animals including elephants and monkeys Leukemia is recognized in rats mice and guinea pigs and these common laboratory animals serve as convenient subjects for the experimental study of the disea e It would seem that with sufficient observation leukemia would become established as an important disease of all mammals A leukemia like disease transmitted by an infectious agent occurs in a number of avian species Little is known about leukemia in reptiles amphibians fish or the invertebrates

In man the age incidence varies with the particular type of leukemia The acute leukemias occur chiefly in children and young adults though no age is immune Chronic granulocytic leukemia becomes increasingly common after the age of 25 and is prevalent at all older ages Chronic lymphocytic leukemia is unusual before the age of 45 and after 50 its incidence rises rapidly paralleling the incidence of the common malignant diseases Monocytic leukemia is u ually seen in middle aged persons (Fig 3)

The leukemias are about equally common in both sexes except for the chronic lymphocytic variety which is three times as common in men as in women

Human leukemia is prevalent in all parts of the world but it seems to be more common in countries that have a higher standard of living and are technologi ally more ad anced Part of the difference may be due to more efficient diagnosis and more accurate reporting in these countries although in the United States leukemia is less common in Negroes than in other races

Leukemia is becoming more common In nearly all countries where reliable statisti s are available there has been a steady rise in the incidence of leukemia which has about doubled itself in the past 20 year Improved diagnostic methods and better reporting are not enough to account for this rise Indeed leukemia is increasing as a cau e of death more rapidly than any other disease except cancer of the lung and coronary thrombosis

The cause of the increas is still unknown Increasing use of x rays in medical diagnosis may play a part but cannot account for the whole picture

Physicians constitute the only occupational group with in reased incidence of leukemia They have about twice as much leukemia as the general population and radiologists who are exposed to small doses of radiation in their daily work have ten times as much a oth r physicians

Survivors of the nuclear bomb explosions in Hiroshima and Nagasaki in 1945 have a definitely higher incidence than nonexposed Japanese Patients given large doses of x rays in the treatment of ankylosing spondylitis a nonmalignant condition affecting young men are found to have a s icantly increa ed incidence of leukemia many after the exposure The above three as oci are the best evidence for the hypothe is that izing radiation can cause leukemia in man Th at present no concrete evidence to uggest other specific factors what they may be is stil ject for speculation

Leukemia is not a familial disea e in the nary sense it is not inherited Indeed a nu of leukemic mothers have been delivered of he infants However there is a slight familial tend toward leukemia patients with leukemia are likely than other patients to have leukemic tives

Etiology Generally speaking the problem u cause of naturally occurring leukemia is not so However some agents are known that can c leukemia in ome species including man

Many attempts have been made to identif infectious agent of leukemia These have been cessful only in birds The prevalent and econ cally important disease of domestic chicken leukemia like condition known as fowl leukosi caused by a virus The disease is evidently ii tious in nature and can be transmitted experi tally from an affected animal to another in the oratory It is not necessary to use living leuke cells to transmit the disea e tissue extracts pa through filters fine enough to remove all an cells and even bacteria are suffi ient The filter agent or virus of fowl leuko is can be cultiv in vitro under very special conditions It will grow in embryonated hen s eggs like so many c mon viru es but will grow in ti sue cultures of c of the natural host Further the virus appear impart neoplastic properties in these cell eve vitro

Since 1951 several investigators ha e been a to transmit mouse leukemia by means of cell f filtrates prepared from tis ues of afflicted anim Only newborn mice seem to be su ceptible to filterable agent and there is a con iderable ti lag before the subject develops clinical evidence the disease Not all the treated animals deve leukemia It would appear that a filterable age probably a virus plays a key role in mou e l kemia but it is probably not the only factor vol ed There is no evidence that leukemia can transmitted in man although transfusions of l kemic blood have been given to nonleukemic p sons

Leukemia occurs spontaneously in many strai of mice and it has a very high incidence in so highly inbred strains suggesting that at least this species hereditary factors play a role Ho ever it is also possible that strictly hereditary fa tors are not responsible but rather that the filte able virus suggested above is tran mitted fro generation to generation by way of the ovum Le kemia can be induced in mice of a susceptib strain as well as in other species of laboratory an mals by exposure to ion zing radiation Sever

chemical gents, includ ng methylcholanthrene in crease th in dence of l uk mi in colonies of s- eptible strains of mice Some naturally occur r g hormo es ha e a simila effect when given in large doses e a co s de able pe iod of time

In man, n relation bet en the ecog ized hor mo es and le kem a is known H wever me e perime ter ha e been able to isolate from the urin of leukemic pati nt sub tan es that produce overgrowth f the bone marrow when injected into guinea p gs. The ub tanc i olated f om patie ts with chro ic gran locytic leukem a bri gs about hyperpla. a of the granulocytic cells f the m r hile th ub tan e i lated f m human ca s f lym hocytic leuk mia nduces hyperplasia of the lymphocyti c ll Th o g n of these substances within the body is n know The re ult of these experim e ts h s ugge ted t the n e tig to s that certain f rm f h m leukemi may be due to overproduction of ne tl e tl e of both of these h rmo l k sub ta ce But as y t there is no real sati fa tory ev d n e to implic te these sub ta es in the etiology of le kem a.

Th re is n co v c ng p oof th t any f the above agents, th th x ept on f i n zing radia tion, pl ys a r l in the a ation f human leu kemia. It is p ob bly best t rega d human leu kem a a s neoplasm a form f can e aff cting th cell f the blood th bone m rrow and the lymph od Th cau f nce i howev r u known, nd t classify l kem a a cancer is not t nsw th quest on f its au t n r doe it mply th t le k mi has the same t logy o a similar o as any th r form f c n er It m st not, t e ampl el se out mi d to the po sib l ty of irus infecti everal i t ertible ancers f e m mmalia spe es udo btedly h e a vir l etiology

It seems likely th t number of fa tors m t cooperat t p oduce le k m a man Pe hap a susceptibl h ed tary o titution is ne e ary upon which one or several external agents must a t to produce the disea e *See* HORMONE ONCOLOGY VIRUS X RAY(S) PHYSICAL NATURE OF

Pathology and pathogenesis If leukemia is re ga ded as a form of cancer the pr mary site of the neoplast c prol fe ation i the bone marrow or the lymph node in the ca of lymphocytic leuk mia No mal blood formi g marrow i about ne half fat and the r m inder on i t of *multiplyi g* and d el ping precur rs f th blood cells red cells white cells and platelets The p n pal *functi of* the red cell i t *carry oxygen to arious part of* the body The *white cells f ari s kind play a* key part *in the ti se re ponse* known a inflam mat on and are import nt i the d fen e of the body again t infect on l y mic o gan ms The pl telets ha e an import nt fun ti n in blood coag lat n They plug mall break in the wall of blood ve sels a d p omote the format n f clots With ut them small wound may bleed unc ntr llably for long p riod

Hype pla a Und r rio co d ti ns the bo e marr w elements may und rg hyperpla a e ve growth In ac te anemia from sudden l s of blood th red cell p ecu sors m ltiply rapidly a d their number in the marr w i crea e notably new ma t e ed ll are thrown t into th cir ulati g bl od pla ng the defi it in sh rter t me th *n* w uld be po ible with ut hyp rpl s S m larly in acut infect ns whe g a ulocytic white lls re mo g nt the ite of fect n fr m the bl od the prec rso of the white ells i the m r row nderg hyperplasi nd pour their m t re ff p ng int the blood These f ms f hyperpla ia ha e a usef l fun t on nd e importa t n *re-* t ring the body qu l b um fter it h been d tu bed a n the example abo by h morrhage o asi by bact ia When the u d rlying c n f the hype plasia no l nge pe at wh n the a em repl ced o the inf ction ed the mar w ret rn t n orig n l co d ti

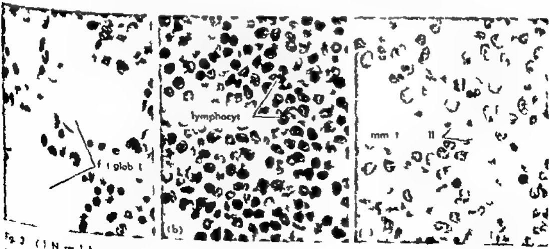


Fig. 3 ( ) N rm l bon m rrow ct h w g variety f c ll nd gl b l f f t (bl k p) ( ) B m w t g o l cyt l k m h w g ly mpl t pl m t by ry imm tu e ll
3 Bon m rr w i h o lymph cytic l k mi # wng ost mpl te pl c m t by lymphocyt

Leucocyte proliferation In leukemia however the hyperplasia of white cell precursors in the mar row differs from physiological reactive hyperplasia by being relentlessly progressive and apparently uncontrolled It is autonomous and is not depend ent on any recognized condition of the rest of the body As the primitive white cells multiply they first replace the fatty tissue of the marrow After a time they replace all of the available fat and pro liferating further begin to crowd out the progeni tors of the red cells and of the platelets Micro copic examination of the marrow shows massively increased numbers of immature white cells at the expen e of red cell and platelet precur ors In ome cases especially of acute leukemia the overgrowth of white cells ■ so ma sive as to impinge upon and de troy the hard calcified tructural tissue of bone producing areas of bone erosion visible in x ray film occasionally painful tumors and rarely frac ture

While the leukemia cells are proliferating in the marrow many of them are being relea ed into the blood Normal blood contains 5 000–10 000 white cells per cubic millimeter in man (somewhat more in most dome tic animals) in chronic leukemias counts of 100 000 are common and counts of more than 1 000 000 have been reported In acute leu kemias the white cell counts are not so high but in the e the cells fail to mature and are relea ed into the blood at an early stage of de el pment In chronic leukemias on the other hand many of the cells released into the blood are fully mature some are of an intermediate stage of de elopment and only rarely are very young forms found

From the circulating blood the leukemic cells colonize the various organs of the body The liver (Fig 4*a*) and spleen are involved early in mo t cases and these organs soon become diffu ely in filtrated with huge numbers of leukemic cells The spleen especially in chronic granulocytic leukemia becomes tremendously enlarged The kidneys (Fig 4*b*) lungs heart skin lymph node and other organs often become infiltrated The leukemic cells continue to proliferate in the e new locations pour ing more cells into the circulating blood As they multiply they lead to enlargement of the invol ed organ and to eventual impairment of its function Generally the increased number of circulating white cells produces few disturbances in the well being of the patient and it is not until late in the course of the chronic form of the di ease that the viscera become sufficiently involved to destroy their function At this time infiltration of the liver may lead to jaundice

Complications due to anemia Anemia is a fre quent complication of leukemia and occurs early in the acute forms As the leukemic cell crowd out the red cell progenitors in the marrow red cell production is impaired Another mechanism also contributes significantly to the anemia The spleen which normally destroys and disposes of red cells at the end of their useful lifespan in becoming in volved with leukemia becomes excessively active and de troys red cells at a faster than normal leading to ■ condition known as hemolytic ane

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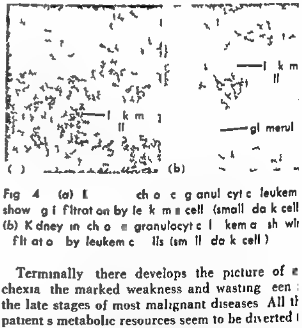

Fig 4 (*a*) L ch o c g anul cyt c leukem show g i filtrat on by le k m ■ cell (small da k cell (*b*) K dney in ch o ■ granulocyt c l kem a sh wi fil at o by leukem c lls (sm ll da k cell)

Terminally there develops the picture of ■ chexia the marked weakness and wasting een the late stages of most malignant diseases All t patient s metabolic resources seem to be diverted supplying the leukemic proce s at the expense the normal vegetati e processes of his body *Se* CIRCULATION DI ORDERS LEUKOPENIA

Course and treatment By definition chron leukemias have a course of more than 1 year fro onset Most cases havi ■ mature cell in the bloo survive a good *deal longer Granul cytic leukemia* average about 3 year and lymphocytic leukemia somewhat longer But the outlook for survi al variable and cannot be predicted accurately in an given case Occasional ca es of chronic lymphocyti leukemia ha e been kn wn ■ survi e in relatively good general health for 10 or more years Othe

es m mb t a compl cat n early the co rse f the di e

Pat ts th acute l k m are u ally q te ill from th t d lly the r ill e p g es rap dl and r l tles ly to a fatal o t m Oc ca l po t r m o s cur especially m h ld en and all evide ce f d ea e may d s appe t a pe od f m ths during wh h the pa t seem e t elv well In t bl howe the process a becomes a t e and the p tient s cumb t ac te l kem a

At th prese t t m le kemia is i riably f tal d p te a a labl t eatment How a gr at deal an be d ne t keep the huma p t ent fe ling ll d r g m t f hi lline In som ki ds f l ke a l fec und btedly be p l ged

Th e are th ba c ki d f t tm t in e r pnt n (1) r d t n (2) d ugs that i t fere with c ll l m lt pl c t n and (3) t d hor

X r k ll l i g c lls d h e the pr perty f affect ng a t ly gr wi g a d pr life ting cell lo d g level th th y affe t mat re ad lt cells Thu r di ti s lect ly k ll m ny leu kem c ll b f re m t of th th body c ll are g h ll i jured H we e e n mall d es of rad t n nj e th n nl uk mi cells of th ma th la g c ll of th bo l a d the g rmi l f the g ad all ap dly m lt ply g lls Suffi ient d g of ad at to kill all the le kem c ll c ot be g e w th ut dest yi g other t ues d d ge u ally l m ted by the d g d e t n rm l bo e ma row ll with t h the i d d l w uld d f em h m th ge o lect n R d at on n be adm ter d ther xternally by me of an x ray mach ne or mi rn lly by gi g th p t nt r d ct o tope Phosph rus-32 i ally u ed Thi el me t accumul tes le t ely n th r p dly gr w ng ell f the bo e marr w wh r its sh rt ra g beta radi t m ks m ny c ll a d pa e m h f the est f the body Rad to i u el s a d d n ger in ute l k mias

In recent y everal dr ha b en de el oped h h m m x ay n the l ct destruc tio f a t ly pr l fe at g cells They t by int f r g w th c rt i b s hem al p ss es necess ary f r ll c ll growth a d ell d io Some f these drug an be u ed s a te le k mi s h oc i lly th y prod c a c mpl t m s- on la t g sev ral month ev n a y r o m r s o d h rm nes r pre ented by co tiso nd a mbe l d t helpf l th sympto- mat c trol of e l f rms f leukem In c te leukem f child en they oc a n lly du e d m t r m i n Th m h n m f a t n f these h rm es in l kemi i t k wn at th p esent tim

[P B H]

B bl g phy W A D Ande s n *P th l gy* 3d d 19 7 W D m hek a d F Gunz, *L uk mia* 19 9 C C d Gru hy *Cl c l H m tol gy* i M d al P t 1958 M M W t B *Cl c l H matol gy* 4th ed 1956

Leukocidin

A s bstance th t de tr ys leuk cytes the white cells f blood Leuk cid s are acellular b- tance which appear i the en nment f certain pecies of gr wi g bacter a They are relea ed into culture media a d th r physical and hemical p pertie gge t that th y proteins

Leuk d n ca l e detected by a variety f method f example by impairment of capacity of le kocyte to reduce methyle e bl e other hydrog n acc pt rs reduct n or lo s of loc mo- t n of leuko yt s alte atio in cellular m rph l ogy a revealed by e minat n f l ing c lls r tai ed pr parations r lea e f ly zyme other enzymes by damag d leukocytes a d fa lu e f l kocytes to ggl t te in the pre nce of ka l n and lkal The mo t th ro ghly t died leuk cidi s are tho e p odu ed by taphylococci nd trepto- cci I mo t inst nce the r ole in tl e ge esis of d ea ha ot been clearly e t bl hed *Se* STAPHYLOCOCCUS STREPTOCOCCUS [A W B]

B bliog phy G P Glad t ne nd W E van Hey ge St phyl coce l le cocidin *B t J Exptl P thol* 38 123–137 1957 E W Todd The leu id n of gr up A h m lytic treptococci *B it J Exptl Path l* ol 23 136–145 1942

Leukopenia

The co d ti of the blood ch ra terized by a de rease n the n mb of cir lat ng white ell or le kocyte It s n t a di e in itself but rather a ymptom It may occ the co se of a gr at ri ty f d eas Its impo tan e n any g en a e d pend o its ev ity nd o the nat r of the derlyi g path log c proce I s m condi t n le k p nia may be id ntal conc mi ta t in others t m y be the ut ta ding feat d t lf a to th eat t lif

The l uk yt pl y n essent al role i the body mech ni m f d fe e ag nst nf ct o by m ny k nd f mi roorg m A m rked d c e th n mber f ail ble white ll weake s th d fe e nd t i the th e t of unc tr ll ble n fect n th t on tit tes the men ce of leukope i

The rm l wh t c ll o t i m n ranges be- tw 5000 a d 10 000 ll per cubi millim f blood Co ts betwee 2000 a d 5000 m mo a n mber of o dit and may n t be f g e t g fic ce h wever u ts b l w 2000 are f g a e impo t Of th th e nds of wh te c lls f d n rm l blood th gra ulo ytes the lym pho ytes d the mo o yt s it the gr n l cytes that l g ly ffected n m st f rms of leuko- p n d th e ell the m st importa t n es t n e t i fect n *S* BLOOD INFECTION

Etiology and pathogenesis Leukop n a oc u s s n c d nt l find ng in a a t d h ter geneo gro p f p th l g c nd t Amo g these t fe t l d g th f b cter al v r l a d pr t zoal f x mpl typh d feve i fl za a d m l a Howe r in m st f the om m n ba te al i fect n th wh t c unt le

Leucocyte proliferation In leukemia however the hyperplasia of white cell precursors in the marrow differs from physiological reactive hyperplasia by being relentlessly progressive and apparently uncontrolled It is autonomous and is not dependent on any recognized condition of the rest of the body As the primitive white cell multiply they first replace the fatty tissue of the marrow After a time they replace all of the available fat and proliferating further begin to crowd out the progenitors of the red cells and of the platelets Microscopic examination of the marrow shows massively increased numbers of immature white cells at the expense of red cell and platelet precursors In some cases especially of acute leukemia the overgrowth of white cells is so massive as to impinge upon and destroy the hard calcified structural tissue of bone producing areas of bone erosion visible in x ray films occasionally painful tumors and rarely fracture

While the leukemia cells are proliferating in the marrow many of them are being released into the blood Normal blood contains 5 000–10 000 white cells per cubic millimeter in man (somewhat more in most domestic animals) in chronic leukemias counts of 100 000 are common and counts of more than 1 000 000 have been reported In acute leukemias the white cell counts are not so high but in these the cells fail to mature and are released into the blood at an early stage of development In chronic leukemias on the other hand many of the cells released into the blood are fully mature some are of an intermediate stage of development and only rarely are very young forms found

From the circulating blood the leukemic cells colonize the various organs of the body The liver (Fig 4a) and spleen are involved early in most case and these organs soon become diffusely infiltrated with huge numbers of leukemic cells The spleen especially in chronic granulocytic leukemia becomes tremendously enlarged The kidney (Fig 4b) lungs heart skin lymph nodes and other organs often become infiltrated The leukemic cells continue to proliferate in these new location pouring more cells into the circulating blood As they multiply they lead to enlargement of the involved organ and to eventual impairment of its function Generally the increased number of circulating white cells produces few disturbances in the well being of the patient and it is not until late in the course of the chronic form of the disease that the viscera become sufficiently involved to destroy their function At this time infiltration of the liver may lead to jaundice

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Resistance to infection As the white cells play a role in resistance to infection it might be supposed that leukemic patients would be at least normally resistant However these patients suffer from more than their share of infectious processes It appears that the neoplastic wildly growing and often immature white cells are not nearly so efficient in coping with bacteria as their normal cousins In acute leukemias especially the very young cells in the circulating blood are ineffectual Unrecognized infections probably contribute to the fever that is so often present in acute leukemia Severe destructive infections about the mouth are prone to occur in acute cases

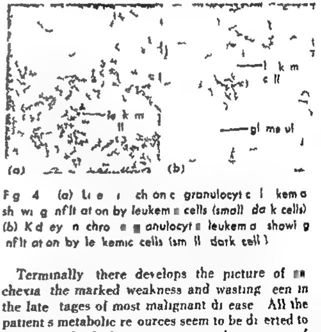

Fig 4 (a) Liver in chronic granulocytic leukemia showing infiltration by leukemic cells (small dark cells) (b) Kidney in chronic granulocytic leukemia showing infiltration by leukemic cells (small dark cells)

Terminally there develops the picture of cachexia the marked weakness and wasting seen in the late stages of most malignant disease All the patient s metabolic resources seem to be diverted to supplying the leukemic process at the expense of the normal vegetative processes of his body *See* CIRCULATION DISORDERS LEUKOPENIA

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Alth gh the m lecular s ze f the polysaccharides formed b diff r t m croorgan ms varies it is al ways h gh, being of the rde of 10 or more The levan are polyfructo e cha ns having u its mutu ally j ined th o gh c b n at m 2 (glycosidal h droxyl) and carb n atom 6 p siti ns therel y diff n g fr m inulin, which ha its D fruct se u its jo ed thro gh c rbo atom 2 nd carb n at m 1 po tio

The microorgan ms e suc ose as a ubstrate b t pol me ize only the fructose molecule to form th levan

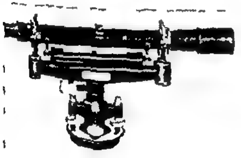
$$(\ )C\ H\ O_1 \rightarrow (C_6H\ _6O\ )\ +\ (n)C_6H\ _2O_6$$

S cros Le an D Glucose

See Polysaccharide. [W.Z H]

Level (surveying)

An instrument f establ shing a horizontal l ne of ght. The level u lly co sist f a telescope and atta hed pir t l el, mo ted t pod f r r ta tion abo t ertic l x The lin of s ght i fi ed by oss h rs Stad a hai s may be p ided fo con m c n keepin f re ht and b ck ight ng l. The t b l pirit l el i l is long and it uppe interior surf ce s grou d to c rcul r arc At t th c ter of the gr und ar is paral lel th the lin of ght thu the lin f ght i h zontal wh th sp t le l bubble i cente ed The in trument s level d by ma ipulati n f fo t sc ew n the m u t ng



Engineer ye l vel

Eng neer le l in lud the dumpy w th tele scope rigidly att hed t the upp rt g y ke and the wye, w th th tel sc pe remo able f om the y ke. A p ec e le l ha a la lev l f ap proxim t l l g nd a m cr m ter s rew f final centering f th tubul l v l b bble Th b bble can be viewed thr gh a eries f p i m wh le the rod s ad

A d S t p c ple s appl ed in self l el ng instruments. Th mag f ng opt al yst m fo e tabl h g the l ne of ght u pended w th n a hou ing by fine w es. Aft g elim a y leveling th footsc a d c ula le el th l n of sight em ns h rizontal f all p int ng Fo th

Her ls n urvey g se Surveyi g

[R H DO]

Level measurement

The dete min ti n of the line r ert cal distance between a ref rence po nt and the su face of a l quid r the top of a pile of di ided olids Since there i little imilar ty between liquid and olid level measureme t they are t eated eparately in th s article

LIQUID-LEVEL MEASUREMENT

S ti f ct ry meas rem nts a po sible only when the liquid is ndistu bed by turbulence w e a ti n When a liqu d is too turbulent for the a erag l el to be r ad a baffl or stilling chamb r i i erted in the tank or v s el to pro ide a at s factory su face

Stick hook and tape gages The e are u ed in open es el wh re the urfa e of the liquid c n eadily be observed Th stick gag i a suitably divided verti al rod or ti k ncho ed in the ve sel

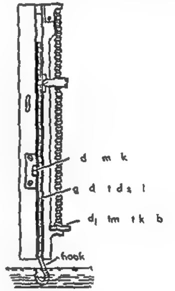


Fig 1 H k g g (From W U w A T I Hyd l M m ll 1912)

th t the m gn t d of the i e d f ll f the level may b mea ured The hook gage (F g 1) p o ides a eedle po nt, which is adj t d to d s turb the l q d u face sl ghtly at the l el read g the eby min m zi g the me us rr r Th t pe g ge e ds th co rrect l el when th l qu d j t to ches the po t f th pl mb b b (F g 2) In mportant r t n f th tape gag th com ple ti n f n lect c rcuit thr h th tape pl mb bob nd l qu d detert th cont ct f th b b w th the l qu d u f e nd lum n t s the n d fo r c e i l bservat n of the liqu d fa

Gage glasses Ma y form of g ge gl s r a l ble f the mea m nt of l q d lev l Liq d in a tank es l i onne ted t the gag gl by u tabl fitt ng and when th t nk i unde p e the ppe end f the gl s mu t b on nected t tl ta k p pa Th th l quid ses t bstant ally the ame he ght in th glas

vated reflecting the increased production of white cells by the marrow and their transport to the involved tissues But even these infections if overwhelming may be associated with leukopenia if the demand for white cells is so great that the resources of the marrow are exhausted

Leukopenia is regularly found in a group of diseases whose only common factor is enlargement of the spleen as for example cirrhosis of the liver The mechanism of this form of leukopenia is not entirely understood Some investigators postulate *a hormonelike substance produced in increased* amounts by an enlarged spleen that specifically inhibits development of leukocytes in the marrow Attempts to isolate and identify this hormone have not been successful

Advanced and widespread cancer may produce leukopenia when it invades the bone marrow extensively and effectively crowds out the white cell producing tissues In this condition known as myelophthisis there is an associated anemia due to the same cause

Leukopenia sometimes severe and *life threatening* is regularly produced by certain physical and chemical agents when they are given in sufficient dosage Among these are x ray benzene arsenic *and a group of synthetic compounds used in the* treatment of leukemia These agents all have the power of selectively injuring rapidly dividing and proliferating cells They thus impair multiplication of the white cell precursors in the marrow which are among the most actively dividing cells in the body Accidental exposure to sufficient dosage of radiation—as from the products of nuclear weapons or of benzene which may occur in industrial exposure—may result in a severe progressive and fatal leukopenia Smaller doses produce a milder leukopenia or none at all The drugs used in the treatment of leukemia and other neoplastic diseases are given in dosages carefully controlled to keep the bone marrow depression within tolerable limits However the leukopenia induced by therapy occasionally becomes a clinical problem

Another chemically and pharmacologically diverse group of drugs many of them in common use rarely or occasionally produce a severe leukopenia in especially sensitive patients although they have no effect on the white cells of the great majority of the patients who receive them Amidopyrine is a well known offender *and several sulfonamides* antihistamines anticonvulsant agents and a variety of others are occasionally implicated The mechanism whereby these drugs can produce such devastating effects in an occasional patient while having no effect on the majority even when given in large doses is not known There is some evidence that it is a hypersensitivity phenomenon related to allergy The leukopenia usually appears after the drug has been given for some considerable period of time or often during a second course *of treatment* with the same drug suggesting that sensitivity is acquired in the manner of an allergy

A considerable number of cases of severe leukopenia occur without any detectable cause and are designated as being idiopathic See ALLERGY ATOPIC LYMPHATIC SYSTEM X RAY(S) PHYSICAL NATURE OF

Course and manifestations The milder incidental forms of leukopenia usually produce no clinical manifestations and will not be discussed further The more severe forms as produced by radiation or chemical agents often present the clinical pictures of pancytopenia or agranulocytosis

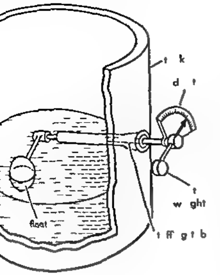
In pancytopenia all circulating blood cells red and white as well as platelets are diminished reflecting depressed production of all of these elements by the marrow This condition can be produced both by the regular marrow depressing agents and those producing hypersensitivity as well as occurring spontaneously The clinical findings are those of an aplastic anemia leukopenia and purpura a bleeding tendency due to diminished platelets Often anemia is the most serious problem requiring repeated transfusion but in other cases repeated and poorly resisted infections due to the leukopenia predominate The cases induced by drugs frequently recover after a variable period of time if the patient does not succumb to infection early in the course but many of those occurring without known cause follow a chronic course for many years Microscopic examination of the marrow in pancytopenia may show either hypoplasia with generally reduced numbers of the precursors of the blood cells or a normal degree of cellularity with failure of the young cells to mature

Agranulocytosis is the name applied to the acute illness resulting from drug hypersensitivity or occasionally from an undiscoverable cause It is manifested by a rather sudden onset of severe leukopenia often with complete disappearance of the granulocytes There is usually no associated anemia or platelet deficiency Most of the symptoms and the high mortality are due to infection by bacteria The clinical onset is often sudden with chills fever marked prostration soon followed by evidence of infection which often takes the form of ulcerative lesions in the mouth The patient may die in a few days of pneumonia or dissemination *of the infectious process throughout the body* With modern antimicrobial treatment infection may be controlled for a time but even so the condition has a high mortality Bone marrow findings are variable and nonspecific but there is always a lack of the more mature white cell precursors

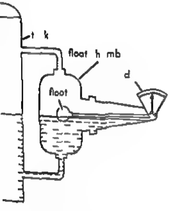
The only treatment that is undoubtedly useful is the administration of antibiotic drugs to control infection These drugs have been life saving in some cases but their effectiveness is hampered by the almost complete lack of the patient s natural mechanisms of defense See CIRCULATION DISORDERS [P B H]

Levan

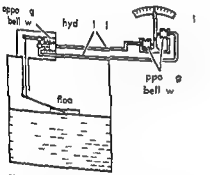
A polysaccharide and a polymer of D fructose (fructans) produced by a range of microorganisms such as *Bacillus mesentericus B vulgatus B sub*



Float-a d l m h m



E t m l fl t-a d l m h m



Float-ope t d hyd l l l g g (D M ne d P ss l m m t d C t l H d McG -H ll 1957)

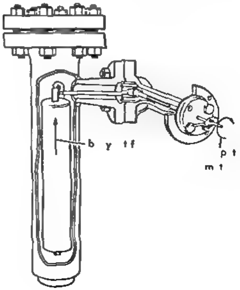
rr s f g eate m gn t de th n with the mech n m B oy t yli de or d pl r prim importa c f ppl c t n l ed und r pr e. As the le l h g s th t a f e devel ped w th t a pp ec movem t f th d pl r Th f t n tted th gh th es el wall by a haft d qu tube flex bl t b r fle ble d

phragm Becau mechanical frict n is mi im zed d placer units a e sensit e to sm ller ch nge in le el th n float units which require tuffing boxes Anoth ad a t ge that l g di placer can be pp rted o short le e a m becau e of the n glig ble tra el with level chang th good de gns can be p id d f r larger le el cha ge than can be rea o ably handled by the fl t and le er sy tem

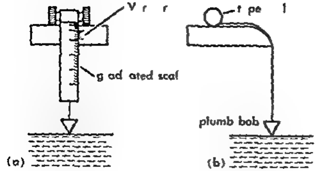
Displacer type l l element are a ailable in m y de igns for b th the int rnal nd e tern l tank installati n I Fig 9 the small m t n f th d splacer i b o ht t of the ta k f meas uring or tr nsm io purpo es by sm ll shaft w thi a t que t l e which supp ts the d pla r I Fig 10 the cha ge in weight f the di place s d tected ext nally by a nozzle and baffle and is balanced by a p eum ti ers

Pressure gages Hydro tat h d may lso be u ed t me ur liq d le el The head f a liq d v ies dire tly w th ts de ity as well as with its lev l and thu this meth d of me sur ment r qui es th t den ty b sub tant ally co sta t De siti s f l quids a y w th tempe at e ro are there f re ntroduced w th t mpe at hanges or the m sur ng elem nt mu t be temper tu e mpen sated Err are al i t od ced if appre iable fl w o ur in the l ne lead g t th he d me s u i g el me t

Mo t pressure me ing el m ts may be u ed n l quid le l i The p r gage is l mited to el tiv ly l ge le el ha ge i pe t nks Mer ury a d a o d m nom t r a b u ed fo nt med at ra ge in cl ed well s pe tank b ca e the nst um nt e b i lly d ff e ti l su m as ing de i s The bell m n meter and sl ck d ph agm gage a b adapted t the m a eme t f sm ll l qu d le el ch ng F d t l n p es e mea ur ng de i s e PRESSURE MEASUREMENT



Fg 9 T q e-t b l l t (F h C)



F g 2 Tape gage (a) Front v ew (b) S de view

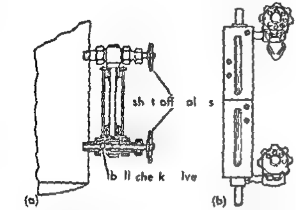


Fig 3 Gage glasses (a) Low pressure type (b) H gh pressure type (From D M Co sid ne ed Process In struments and Controls Handbook McGraw H ll 1957)

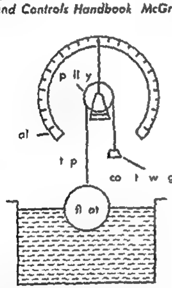


Fig 4 Float tap a d pulley gage (D M Cons d ne ed Proces In truments and C nt ls Handbook M Graw H ll 1957)

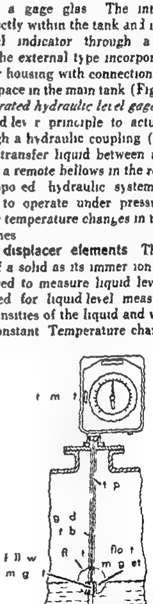
as in the tank and this height is measured by suit able scale In order to avoid errors due to capil larity gage glasses with an internal diameter smaller than ½ in are not recommended unle s a correction is applied Mo t gage glasses are equipped with shut off valves to permit cleaning and replacement of the gage glass without empty ing the tank and with check val es to prevent lo s of liquid in the event of gla s breakage Low pres sure gages are cylindrical glass or plastic tubes high pre ure gages are metal tubes with thick glass windov s (Fig 3)

Float mechanisms Various types of float mech anism are also used for liquid level measurem nt. The float tape and pulley gage provides an excel lent method of measuring large changes in level with accuracy (Fig 4) It has the advantage that the cale can be placed for convenient reading at any point within a rea onable di tance of the tank or ves el It can be applied to the mea urement of liquid in tanks under pressure but frictional errors are introduced in bringing the tape through the wall of the tank One solution is to maintain the tank pressure over the entire length of the tape and read the tape through a glass Another olution is to introduce a magnetic coupling between the float which is under pres ure and the tape actuator which is at atmospheric pressure (Fig 5)

Float and lever mechanisms The y may be u ed advantageously in closed tanks under pres ure when the liquid measured is vi cous or when it would foul a gage glas The internal type is located directly within the tank and is connected to an external indicator through a stuffing box (Fig 6) The external type incorporates an auxil iary cage or housing with connections to the liquid and vapor space in the main tank (Fig 7)

Float operated hydraulic level gage This utilizes the float and lev r principle to actuate a remote gage through a hydraulic coupling (Fig 8) Float movements transfer liquid between a transmitting bellows and a remote bellows in the receiving gage A dual oppo ed hydraulic system permits the mechanism to operate under pressure and com pen ates for temperature changes in the connecting hydraulic lines

Buoyant displacer elements The change in buoyancy of a solid as its immer ion in a liquid is varied is used to measure liquid level This prin ciple is u ed for liquid level measurement only when the densities of the liquid and vapor are ub stantially constant Temperature changes will pro-



F g 5 Magnet c typ flo t gage (F che a d P r te Co)

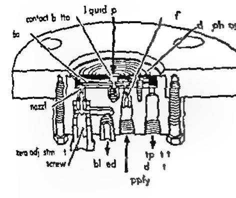


Fig 14. F rce-bal n d ph ogm-typ le l t a s- tter (T yl f st f C)

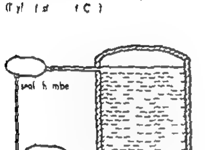


Fig. 15 Me ury m m te w th l q d al tank (T yl I stru t Co)

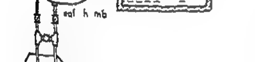


Fig. 16 Gas-p ge y tem f l l m u m t in closed to k D d ff t l p g l t R ro e with dl l a d S l a ed e ch be ff q d (F om D M. C d d Proc ss I str m t nd C t f N db k M G w H ll 1957)

the purge gas flow The bottom edge of the dip tube or box is de gned to nimim ze the size of the bubble relea ed

When the liquid being measured is h ghly cor ros e or conta ns solid particle and the gas purge is not sat sfactory a liquid purge a m mbi at on ga and l qu d p rg or a combinati n air and team purge is p s ibl

The pre ure l ead f a liquid above a reference po nt may al o be mea ured by a force-balance diaphragm y t m As the l el varie the dia phragm operates a en itive detector s ch as a nozzle and baffl and a s mple servo to produce a f r e equ l to that de el ped by the l qu d head (Fig 14) The diaphragm is ma ntained n a sub t ntially consta t p siti n Th impl t y tems are pn umatically ope ated and the pre ure op- po ing the l q id head s equal to it Other system pp the hydro tat c h ad on the diaphragm with p e s r n a bell ws of reduced are n that the p e u e change f r a g en level ha g i magn f ed Th fo ce-balance d aphragm y tem el m n tes the pu g y tem and its ma ntenance p ob- l m

Clos d t ks When ma meters other d ffer ent al pres ure elem nt are apj l ed to level meas- r ment i l d ta k a ec nd onne tion mu t be m de to th tank at a high r le el (Fig 15) N rmally the d tan e b tw en th tw ta k c n necti ns s qual t th c l b ted range of the man m te d id d by the d ffe nce b tween the d ty f th l qu d and th ap r in th tank The xt rn l leg is filled w th liquid to e l ch m ber at th upp r c nn cti n in the t rk to a id th un ert nty d e t o den at on nd p sible o e fl w into an n filled leg Thu er pres ure occ r when th liq d n the tank s at the upp r level a d th m x mum p e s re i read wh n the l q id n the tank t the l w r conne tion r the ef r n e l el To a oid onfus on i th erv c th ma met al br ted n r e s that it r ad z r when the tank liqu d s t th r fe en e le l Tempe ature change on th xt rnal leg au e re d ng err r nd t r al leg ha e been u d t oid th t o ble The d fferent al p e u e m a u i g elem nt may be e m tely loc ted f om the tank so that l ad l ne err r a a o d d

G s-p rge y tem (F g 16) are lso u ed for l el m a urem nt n clo ed tanks Both tank c n necti n a e s ppl ed w th ga t pr ssu e sl ghtly h ghe th n the ma mum wh ch c n occ r n th t nk Th gas flow a l m t d by estri ti n or ne dl al nd a e oft me u ed by rot mete s Th ga flow n each lin mu t be larg n ough to p nt l quid from ntering the lead l nes and to e ure a c t d ngs It mu t be small en ugh t k ep th pres u drop between th ma ometer t p and the t nk at a minimum Th m nom t r n t ns (taps) a e lo ated s lo e to the t k nnecti n a pos ibl

Liq id als ar occas o ally used on lo ed t nk l qu d l l m asu ments Seal ch mbe m t be

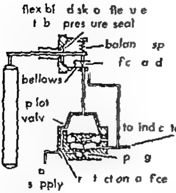


Fig 10 Force balance level unit (D M Considine ed Process Instruments and Controls Handbook McGraw Hill 1957)

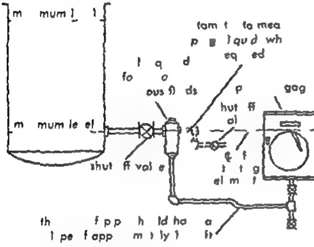


Fig 11 Pressure gage measuring tank level (D M Considine ed Process Instruments and Controls Handbook McGraw Hill 1957)

Open tanks In open tanks the pressure measuring element is connected directly to the tank at or near its bottom (the reference or datum point) The pressure element may be located at any reasonable distance from the tank and at any desired distance below the reference point but the element responds to the additional head due to the liquid in the lead line Gas or vapor must be vented from the lead lines Pressure measuring elements when used in this way normally have suppressed ranges so that the zero reading occurs at the pressure corresponding to the bottom of the tank level With careful installation the pressure measuring element may be located above the reference point This installation requires a gas tight lead line venting only when the tank level is high and the maximum safe elevation of the pressure measuring element is the head corresponding to one half of atmospheric pressure less the vapor pressure of the liquid (Fig 11) Temperature changes on sloping lead lines cause density change and errors are introduced unless the pressure element has special compensation for this effect

To minimize lead line errors and venting trapped gas and gas purge systems have been developed These systems make it possible to locate the pressure measuring device at any reasonable distance above the reference point The diaphragm box may be installed directly in the tank or connected to it at the reference level A slack diaphragm separates the liquid from the trapped air or gas leading to the pressure gage The diaphragm has no spring constant hence the gas pressure equals that at the reference point and the remote gage indicates the head of the liquid with respect to the reference point (Fig 12) The gas volume in the pressure measuring system is kept small to minimize the temperature effect and the compressibility effect with liquid level changes

On some installations a trapped gas system eliminating the slack diaphragm can be used On these installations the gas must not be absorbed in the liquid and the liquid must not vaporize and condense in the lead line to the pressure measuring device Provision is generally made for periodic gas checking and replacement In the gas purge system (Fig 13) a small quantity of gas is bled into the system continuously This gas is permitted to bubble from the box or a tube with an opening at the reference level Purge rates of about 1 standard ft³/hour are common Precautions are taken to avoid measurement of the pressure drop due to

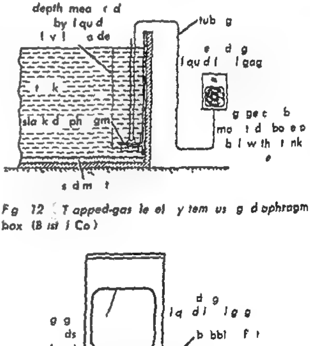


Fig 12 Trapped-gas level system using diaphragm box (Bristol Co)

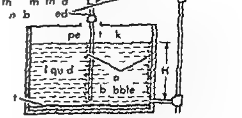
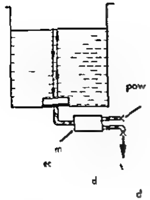
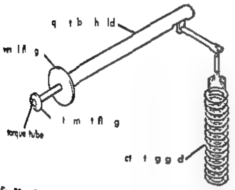


Fig 13 Gas purge level system (Bristol Co)



ig 21 So l l g g (D M C d d P s Instrume t d C t I H db k M G w H ll 957)



Fg 22. Grid-typ l m t (U O I C f C I lv)

SOLIDS–LEVEL MEASUREMENT

S lids le l detect rs are u ed to locate the top of a pile of d ded l d in large ves els r pr ce s i g equipment The in truments are de ign d for the differe t l d handled and the in tall tion m t be car fully made to i ure pr per measure me t Be u e l ds fu nel c e and ary n a erage d ity w th the particl i e hape di tribut n m ture c ntent nd other fact s these dete t rs pr ide nly an appr ximat indicat on f the olume prese t or the top f tl e p le S l ds l el d tector are cla sified as o tini o s or fixed p nt

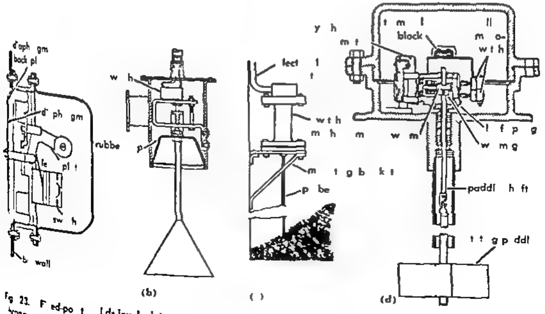
Continuous detectors These pr ide co t nu ou mea rem nt of the l el o e the ange for which they were de gned Th u tput i a a alog repr entat n f the le l of the l d

The grid type eleme t (Fig 22) m ed n bed of finely d id d movi g particle and pro de cont nu s i d cati n of the lid urface The g d supp rted and weigh d by a n e t nal pn um t c sy tem the weight i crea ng as the mme on i c ea e Th s c tr cti m y be u ed i e l u der p e t

The γ ray mitter and det to di c s ed p e ly nd liq id l el mea rement is part cu la ly u eful n tl s rvice bec u e all the equip m nt may be loc t d out de the es el

The beam cale and oth r weigh ng de ce are sed part cula ly on mall m ls a d pro es ing eq pm nt *S e* WEIGHT IEASUREMENT

Th capa t n e type le el dete to al o dis cu ed und l quid le el m s em t m satis f tory for use on m ny finely di ded solids



Fg 23. F ed-po t l ds-lev l d t ct ( ) D hragm-ope at d l l d t t (B n-D f C) b Pend nt one-type l l d t ct (St ph s-Ad m Mfg C) ( ) P obe-d fl ct typ l l d t t (G B L d m C) (d) R t t g m ddl wh l-typ l l d t t (F ll C)

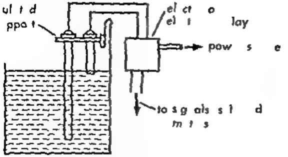


Fig 17 Conductivity probe type level system (D M Considine ed Process Instruments and Controls Handbook McGraw Hill 1957)

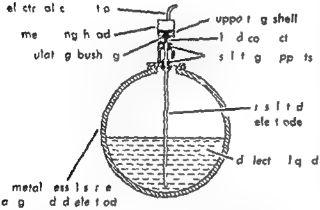


Fig 18 Capacitance probe type level system for dielectric liquid (D M Considine ed Process Instruments and Controls Handbook McGraw Hill 1957)

installed at suitable locations and consideration must be given to the differential in the specific gravity between the sealing liquid and the liquid in the tank

Thermal elements may be used for level control when the temperatures of a liquid and of the vapor space above it differ appreciably Although standard thermal elements are used in some services a number of special designs offered for boiler service are particularly designed to handle the problem of boiler swell on increased steam demand The level devices in this group are not precision devices *and are not used for measurement purposes*

Electrode or probe systems These are used in various forms for level indication and control (Fig 17) The number of electrodes and their design depend upon the characteristics of the liquid and the application Fundamentally a circuit through a relay coil is closed (or opened) when the liquid contacts a probe Electronic circuits are used when *the liquid resistance is high*

Capacitance measuring devices If the liquid being measured is a dielectric insulated probes may be inserted into it and the capacitance of the assembly will vary with the immersion of the probes *in the* liquid (Fig 18) The dielectric constant of the liquid must be different from that of the vapor and errors will occur if either of these changes appreciably If the liquid is a conductor only one probe is necessary but it must be covered with an insulating coating (Fig 19) As the liquid rises the probe the capacitance of the unit increa Although capacitance methods of measuring liqu have certain advantages (no moving parts corr sion resistance) they have certain disadvantag such as high cost susceptibility to dielectr changes and susceptibility to electrical interfe ence *Therefore this method of level measureme* is limited to those applications which cannot readily handled by other means

Nuclear level gages These are used for difficu applications Basically all of the units involve *source of gamma (γ) radiation and a detector sep* rated by the vessel or a portion of the vessel which a liquid level varies As the level rises th detector receives less γ radiation and thus th level is measured Numerous designs are availab for special application needs one of which illustrated (Fig 20)

Sonic level detector This is based on the tim *increment between the emission of a sound wav* pulse and its reflection from liquid surface Th sound wave pulse is generated electronically an its time in transit is measured very accurately b electronic means If the speed of sound in th liquid or in the vapor is known accurately th liquid level is known (Fig 21)

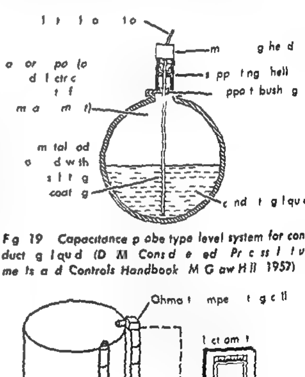


Fig 19 Capacitance probe type level system for con ducting liquid (D M Considine ed Process Instru ments and Controls Handbook McGraw Hill 1957)

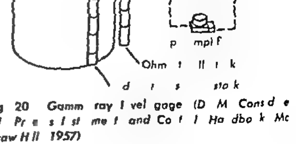
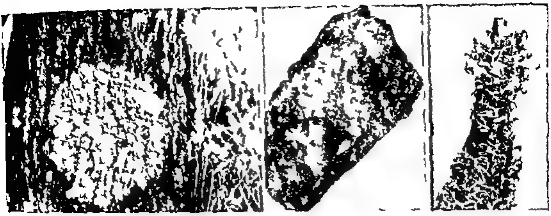


Fig 20 Gamma ray level gage (D M Considine ed Process Instruments and Control Handbook Mc Graw Hill 1957)



A l f ose l h P mel Ni t th p h ped p o t b h (F m H J F ll d O T pp produces a bod (b) C ust l h g w g po C ll g 8 t y d H (t 1954) rock. (c) Usnea b bat frut l h g w g

hese masses of c lls and hyphae the pl t body as be f l (le fl ke) r sto e (ru tl ke) m fru cose (b ch n)

Reproduction R p d tio by f gmenta tion, eithe by the death of the old r p rts f the parent body o by pec l bod called o ed which are mall f gme ts f the th ll r ad ly de hed and d emi ated by a r cu ent In ad dition to th egetat e m ans of rep d c ng the li hen a t e h f the di idu l compo e t ma reprod e e th exually r sexu lly

Economic importance Th l h s a impo tant p ee soil b ld a fo d f r man d other anim l a o c f a h dy s l tm w b l a d eudbea f ia n and a t ur e f ertain t l ls ed f th i erimati app l S ALGAE FUNGI [P s] B g phy S e THALLOPHYTA

Licorice

A p od t obt ed f m the lic i pl nt *Glycyr rhiza glab* f the l gum family (Legum s e) It is a per l herb wh ch gr w both w ld and u cul tion i s uthern Europe a d in w tern a entral A a The r ts a d ed for eral m th and the p sk ged for hipment Spa n leads in the p od ti n f c lti ated l cor ce r ot Licori e is used in med c n t m sk objecti n ble a d as a la ati e as a fl i g m te l in the b ewing toba c nd ca dy i du t s and in th manuf ctu e of ho p li h S ROSALES F LA A D FLA ORI S [F D S]

Lie detector

A useful appl cati n f the physiolog c l resp s of emotion. The machi e is known as th p lygraph lie d ector and i w d ly u d i m ime d te ti n and in sec ty se s ti ea e s f empl yment The li d tect r pe ates the pri c pl r ssumption that lyi g n ol s n emot al re-sponse and that emoti n l re ct ns e char ct ized b phy l gi l change The phy l gical manifestations m red by l e d te t rs changes in relat ve bl od pres ure hea t rate re pi ati n mo m nt and frequ ntly palmar sweati g o gal a c kin esp ns The ne essary apparatus is att ched to s pect who is then asked a ries f q e t ons t which he c n s mply nswer y or n Some f th q est ns ar n t l and serv to e tablish th ubject s characte sti re pon es to kn wn truthf l swer The significant qu tions o th wh ch pe tain t the rime a e phrased s th su pe t must either admit knowledge f th r m l e

Lying i b lie ed to i l e mot onal re-p n beca e f the onfl ct between the trong cultu d c nd t ng fo tr thfulnes and th de-re to cape dete ti n Pers ns lack ng on sc en may till m ke an m tion l r sp n t lyi g if th y belie in the i fallib lity of the m hin

Ac rd g to r ew m de by D l W lfle in 1946 the c racy of the p lyg aph in pract 80% c rrect 3% wrong nd 17% not terp t able Th ac ur y depe ds t a gre t xtent on the skill f the ex mi er who must be tho oughl t ined and hould h ve e e al y ars f e pe ence

M st ourts do n t yet acc pt li detect re-port a eviden lth gh onfe ions el cited by me f a l e det tor xaminat on may usually b epted [A F A]

B bliog aphy F E Inb u *Lie D tecti n d Crim nal I t r g t on* 2d ed 1948 *The Poly g aphic T uth T t A sympos um* T nessee Law Review 1 22 Febr ary 1953 D W lfle Sum mary f r port of ub omm ttee on m thod of l e detect n *Am J Psychol* 59 544 1946

Liesegang rings

Pe od c ecip tat n one hta d l y counte diffus on f solubl ub tances wh h f rm a slightly ol ble prec pit te I th se of ne d mensional d ff si th e zon s ar alled Li eg ng band

Whe placing a drop of c ncentr ted s l er n t te s l ti n on n el s plate

Fixed point detectors These indicate when a specific level has been reached They are u ed mainly for actuating alarm signals By installing a *number of these however at different points the* combined respon e can be made to approach that of a continuous detector Four fixed point detectors are shown in Fig 23

Diaphragm operated level detectors are widely used for finely divided solids (such as wheat) in open vessels

The pendant cone and movable probe units used in large open vessels are actuated by the surface *of the cone resulting from the piling of the material*

The rotating paddlewheel level detector is driven continuously by a small motor until the paddle is stopped by the presence of solid material This device is widely used on finely divided solids in open ve sels [R E CL]

Bibliography D M Considine (ed) *Process Instruments and Controls Handbook* 1957

Lever

A pivoted rigid bar used to multiply force or mo tion , sometimes called the lever and fulcrum (Fig 1) The lever uses one of the two condi tions for static equilibrium which is that th sum *mation of moments about any point equals zero* (The other condition is that the summation of forces acting in any direction through a point equals zero *See* INCLINED PLANE)

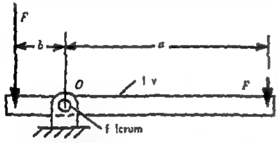


Fig 1 The lever p vots at the fulcrum

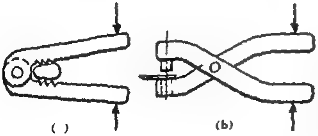


Fig 2 (a) Nutc acke (b) Paper Pu ch

If moments acting counterclockwise around the fulcrum of a lever are positive then for a friction le s lever

$$F_B b - F_A a = 0$$

thus

$$F_B = \frac{a}{b} F_A$$

If F_B is the output and F_A is the input the ı chanical advantage is

$$MA = \frac{F_B}{F_A} = \frac{a}{b}$$

Applications of the lever range from the im nutcracker and paper punch (Fig 2) to comp multiple lever systems found in scales and in t ing machines u ed in the study of properties of r terials *See* SIMPLE MACHINE [R M Pl

Libra

The Balance in astronomy is one of the 12 zodia con tellations Libra appears during the pring is the seventh sign of the Zodiac The con tellati consists of faint tars and is not conspı uous lies just west of the claws of Scorpiu The pr cipal stars outline a four sided figure re embling balance with beam and pans The balance mig have been held originally in the hand of Virgo zodiacal constellation nearby who was identifi with the Goddess of Justice Another possible re son for identifying the constellation with the ba ance is that 2000 years ago the Sun was in Lib at the then autumnal equinox at which time da and nights are of equal length *See* CONSTELLATIO [C S Y

Lichens

A group of organisms having a dual nature th is algal and fungal components are combined in a plant that is distinct and consistently recogniza ble Over 15 000 species have been described Be cause of the dual nature of lichen they do no readily assume a natural position in any plan classification They are widely distributed and oc cur in a great variety of habitats Lichen may b found on bare rocks soil living tree trunk and dead wood of any kind They range from the arcti tundra where some species are found in such abun *dance as to provide pasturage for grazing animal* to the tropics where some of the bark lichens ar conspicuous Frequently they are to be found where conditions are unfavorable for the growth of other plants Most lichens are gray or grayı h green bu some are white orange yellow yellowish green brown or black In a few certain structural fea tures of the plant are brilliantly colored

Relationship The complete relationship which exists between an alga and a fungus as ociated in a lichen is not fully understood The relation hip has been cited as one of the best examples of sym biosis within the plant kingdom ; however some students of the group are not convinced that this is a reasonable explanation

In most lichens the algal component is a member of either the blue green algae (*see* CYANOPHYTA) or the green algae (*see* CHLOROPHYTA) The fungus component is usually a cup fungus (*see* ASCO MYCETES) or more rarely it is a club fungus (*see* BASIDIOMYCETES) The fungus usually forms a dense netw rk of interweaving hyphae enveloping the algal cells Depending on the configuration of

A folose l h P m l N t th c p h p d po a t b ch (F m H J F ll r e d O T ppo prod ch bod (b) Cru t l h g w g p C ll g B t y d H lt 1954) rock. (c) Um b bat f n l h g w g

ee masses of c lls d hypha the pla t b dy a be f lose (l afl ke) cr t e (tl ke) or uticose (b an hin)

Reproduct on R p d t s by fragm ta on, the by th d th f the lde part of the arent bod o by p al b d c ll d o d hich a e sm ll f gments of th thall s ead ly ta hed a d d m ated by air c ents In ad ion to th g t t mean of r p od c ng th i hen as a u t h f the i d d l comp e t c rep odu e ith sex ally or e ally

Economic importance The l h n re imp ant p eer so l b lde s as f d f r m d ith an al a e f h dyes l tm nchil d c dbe a so of ta n d as so e f rt e ti l o l u d f th m t app l S ALGAE FUNGI [P A V]

B bl g phy S THALLOPHYTA

Licorice

A p od t bta ed f m the l c pl nt *Glycyrrhiza glab* of th legume fam ly (L gum o) It a p renn al he b wh ch gr w both w ld and n cult t n thern Eu op nd i we t rn A d ents l A The roots a e d ed for s al e h a d the p ckaged f r sh pment. Sp in leads in the p od tion of ult ated li ori e r ts Licorice is used in med cine t m k obje t on bl tr e and s a lax t e a fi ing mate l i d brewing t b d a dy indu tri nd n th m uf t re f h e p l h See ROSALES SPICE AND FLAVORI G [P D S]

Lie detector

A e ul pplicati of the phy logi l resp s of emotion. Th m ch ne i k own s the polygr ph lie d ect and is wid ly used i r me det ct n and in secur ty se ti e re s f employment

The li d tector ope te n the p i cipl assumption th t ly ng i ol es n mot on l e ation and th t emot nal r a ti re ch ract ed b phy l l change Th phy ol g al ch a es m red by l e d tect r a h ng relative blood p e e heart rate respiration mo ements and f eq e tly palmar sweating o gal kin re po The neces ary apparat is atta h d t a uspect wh i then asked erie f questions to wh h he can mply nswer y s or no Som f the q est s re ne tral and serve to e tablish the subject s ch racteristi respo s to k wn truthf l swers Th s gnific t que t or th which p t n to the r me are ph sed th suspect must e th admit k owledg f the crim a lie

Ly n belie ed to in l e a emotional re sp beca e of the flict b tween the strong ltured diti g for t thf l es and th de ire t e cape detect n Per ns lack g a n ce m y st ll m ke a em t n l re p nse t lying f they belie e the i f llibil ty of th m chi

Acc d g to a eview made by Dael Wolfl in 1946 th ccur cy of the polyg ph n pr ti e 80% o re t 3% wr g a d 17% not terp t able The a curacy d pend to a gr at e tent on the k ll of the exam ner who m t be tho ughly t i ed d sh uld h e sev al ye rs f e p ri nce

M t court do n t s yet acc pt l e dete t report s e dence lthough conf ssio s el ted by me ns of a l e d t ctor exam ati n may usually be cepted [A F A]

B bliog phy F E Inb u *L e Det ct n a d Crim nal I terr g t o* 2d ed 1948 *The P ly g ph c T th Te t A sympos m* Tenn sse Law Review l 22 Feb uary 1953 D W lfle S m mary of r port f sub ommitte on method of l detect on *Am J P ych l* 59 544 1946

Liesegang rings

P iod prec p tat n s es bt ined by o nte diff i n f sol ble b ta ce whi h form a lightly l bl pr ipitat I the cas of n -d me n l d ffus n th e zo a e lled Lies g g bands

Whe plac g drop of a once trated s l n tr t s l tio up a gl pl t co ered w th a

gelatin layer containing potassium dichromate R E Liesegang observed in 1896 that the resulting precipitation of silver chromate did not spread continuously or quasi continuously but that individual precipitation zones separated by zones free of precipitate evolved in the form of concentric circles Similar phenomena have been observed with many other reactions

Periodic precipitation is due to the interplay of diffusion and nucleation which requires a certain degree of supersaturation Assume that solute A diffuses from a fairly concentrated solution into a dilute solution of B The precipitate AB starts to evolve the initially high degree of supersaturation drops and accordingly nucleation ceases Upon diffusion of A into farther regions not yet depleted with respect to B a sufficient degree of supersaturation is reached once more a second precipitation zone evolves and so forth *See* PRECIPITATION (CHEMISTRY) [C W]

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Life origin of

The origin of life refers to the means by which living organisms arose on the earth which contained no life when it was formed While there is little difficulty in telling whether a higher organism is alive there is no agreement as to what characteristics would be required for the most primitive organisms in order to call them living The most outstanding characteristic of living organisms is their ability to reproduce Therefore the definition used here for a living organism will be an entity which is capable of making a reasonably accurate reproduction of itself with the copy being able to accomplish the same task Furthermore this organism must be subject to a low rate of changes (mutations) that are transmitted to its progeny

Spontaneous generation Until the nineteenth century it was almost universally held that life could arise spontaneously as well as by sexual or nonsexual reproduction The appearance of various insects and animals from decaying organic materials in the presence of warmth or sunlight was a common observation but this observation was misinterpreted to mean that the insects and animals arose spontaneously

The Tuscan physician Francesco Redi performed the first effective experiments (1668) to disprove the hypothesis of spontaneous generation He showed that the development of maggots in meat did not occur when the flask containing the meat was covered with muslin so that flies could not lay their eggs on the meat Lazzaro Spallanzani performed similar experiments (1765) showing that microorganisms did not appear in various nutrient broths if the vessels were sealed and boiled Objections were raised that the heating had destroyed in the broth and air the vital force which was postulated as necessary for life to develop By readmitting air it was possible to show that the broth could still support the growth of microorganisms But Spallanzani could not demonstrate that the air in the sealed flask had not been altered and the doctrine of spontaneous generation persisted widely

The problem was finally solved by Louis Pasteur (1862) who used a flask with broth but instead of sealing the flask drew out a long S shaped tube with its end open to the air The air was free to pass in and out of the flask but the particles of dust bacteria and molds in the air were caught on the sides of the S shaped tube When the broth in the flask was boiled and allowed to cool no microorganisms developed but when the S shaped tube was broken off at the neck of the flask microorganisms developed These experiments were extended by Pasteur and by J Tyndall to answer all objections that were raised and the doctrine of spontaneous generation was finally disproved

Origin of life theories Shortly before 1858 Charles Darwin and A R Wallace had published simultaneously and independently the theory of evolution by natural selection This theory could account for the evolution from the simplest single celled organism to the most complex plants and animals including man Therefore the problem of the origin of life was no longer how each species developed but only how the first living organism arose To answer this question a number of proposals have been advanced

It has been proposed that life was created by a supernatural event This has been a common belief of many people based on a literal interpretation of the first chapter of Genesis which describes the creation of all living organisms by a direct act of God This type of proposal is not considered by most scientists since it is not subject to scientific investigation

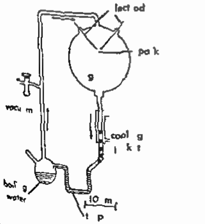
In 1903 S Arrhenius offered a second theory that life developed on the earth as a result of a spore or other stable form of life coming to the earth in a meteorite from outer space or by the pressure of sunlight driving the spores to the earth One form of this theory assumes that life had no origin but like matter has always existed The presence of long lived radioactive elements shows that the elements were formed anywhere from 5 to 12 × 10 years ago If the elements have not always existed it is difficult to understand how life could have always existed Another form of this theory assumes that life was formed on another planet and traveled to the earth This hypothesis does not answer the question of how life arose on the other planet In addition most scientists doubt that any known form of life could survive for very long in outer space and fall through the earth s atmosphere without being destroyed Therefore while this theory has not been disproved it is held to be highly improbable

A third hypothesis held that the first living organism arose from inorganic matter by a very improbable event This organism in order to grow in

m mo gan en iro m nt w ld h t synth ize ll f t ellul r c mp n t f m carb n dioxide t and the in g ni tr nt P e e t knowl edge f b och mi try h s th t even th mple t b en re e t mely c mpl x and th t the p ba b ity of th po ta e g ne t n f a cell f m rgan c mpound s a gle e t is mu h too small to h e curred in th ppro imately fi bil ion y ars e th arth fo matio

A r pl bl p p l th t l f ar se sp n ta eo l in the oce n f the primiti e e rth which co t ined l g q t t s of o g m p nds mil t th whi h m l r g nism Th the ry a utlined m nly by A I Op n (1938) d form th b s of mo t f th pre t id s o the igin of l f Opa n g d that f large m ts f o g nic c mpo nd were in the ocea. f the p imit earth these rg c m pounds ld r t t form t uct re f gr ater a d gr te c mpl xity til t t wo ld form h h ld be called l ving In th w d the evoluti f the first l g o gan sm w ld i ma y nb l ical tep nd n e f these e ts uld be h hly imp bable

Oparin also p p d th t ga mp und might ha been f rm d the p m ti e th f there red ing atm phe f m th e am t d hyd oge i te d l th p nt during tmo ph f b n d d t ge gen and w te H C U y (1952) pla d the forming tm ph theory fi m f dat n b th ing th t meth n mmo a, a d w te e the tabl f rms f l n t og a d yg n f the es of hyd g n p e t Co m c d t th d fr m wh h th e rth i b l e d t h been f rmed ntain a great e f hyd g n T pl net J p t S t and U a k w to have atm ph of m th d mm n a O during d t h devel p d Me ry Ve s th Earth d Ma s d t the p f hy



Apparatus used f p od ct f m id by e discha g Wat b l d m ll fl k ses th gase l g fl k wh p k l t d products of th disch rg d d p th gh tube, nd oc l t m ll fl k

d n f ll w d by th pr du tion of oxyg n by the ph t h m l pl tt g of wat r There has not b n uffi ent t me f th hyd n to ha e e p d f m J p te Satu U Nept n and Pl t w g to th lowe temp t d h her g t ti nal tt t n

Origin of organic compounds M y tt mpt ha b n m d t ynth e rg i mp d u d r xd d t n u g ca b n d de and water with va f n gy h s ultra iolet li ht ele tri di h rg d h h n e gy adiation All of th e expe m t f led t g e org nic compo nd e cept i e t m ly sm ll y eld

S pp t f the ideas of Op a i and U y me from xpe m t by S L. Miller (1953) H showed that m t re f meth ne ammo ia w te d hydr ge wh n bjected to an electr d h e s gnificant y ld f mple ami acids hyd y ds aliphatic a d ea nd p s bly s g Ult v let l ght gi es m l lt

O th b f the e e p m t t s thought th t a io g mp unds (u h ami o a id hyd y ac d l ph t ac ds a d ug s) w e pre t n the ce f th p mit th It t ll ec sary t h w me ha m f the f mat o f p lypept des p n d py m di (th e wh h u n l ds) n leo- t des and p lynu leot d o r l pho ph te b nd e e gy (n de e t pl phat) yn thes f p lypept d w th talyt ti ty (zym) a d the de l pm t of p ly le t d p ble f lf d pl t n

Nature of first organisms In p t l o n m th d pl t p ceed by d pl ti th g f ll w d by s th f m e zym d th ell n t t t d d f th c ll i to two f gm t The g wh h l c t d n the h m m mp ed f p ly leo- tid all d d de xyr b nucl d S CHRO O SO E GENE NUCLEIC ACID

S n th e tal h t r t f l g ga m i th ability t d pl ate t h s b r p o- p d th t th fi st l g o g m w e mply tr p f deoxy bon le a d (o p h p t p f b nucl c d) wh h t geth w th th v nzym s uld d pl t Th g n m would be m l t u pt th t t w ld h th e e ry nzymes f r it ep od cti n Th v s t f e l t p f n le d r d d by t f p t Th u s p bl f d pl ti n b t ly w th n ther l ll whe th r m k s u f the ll zymes d m tab l m S n e th u an e- p d e t elf b t ly w th n l n ll th r i d bl d p t t wh th a u h uld b lled l g t In a y c y l g t bel e that th s w t th t typ of l g g n m b t th t t gr s n f m m d ed type f g m S e VI US

It h b p p d by A I Op in that th t g m w c rv te p t l tead of

strips of polynucleotides A coacervate is a type of colloid which forms two phases one of the solution and one of the coacervate instead of a uniform dispersion as with most colloids It is assumed that there would be some coacervate particles which could absorb proteins and other substances from the environment grow in size and then split into two or more fragments which would repeat this process In time the duplication would become more accurate and the genetic apparatus of nucleic acids would then develop *See* COACERVATION

These ideas about the nature of the first organisms are based on the assumption that the first forms of life were similar to present organisms in their basic chemical composition All present organisms contain proteins nucleic acids carbohydrates and lipids While the assumption may be incorrect it is the best working hypothesis until it can be shown to be inadequate Other possibilities for the development of the first organisms can be enumerated but so little is known of the composition of the primitive oceans that such speculation is not profitable

Heterotrophic organisms While little can be said about the development of the first living organisms reasonable hypotheses can be made for the development of the simple bacteria algae and protozoa from the most primitive organisms The theory that the primitive oceans contained large quantities of organic compounds implies that the first organisms were heterotrophic Heterotrophic organisms do not synthesize their basic constituents such as amino acids nucleotides carbohydrates vitamins and so forth but obtain them from the environment Autotrophic organisms synthesize all their cell constituents from CO_2 H_2O and other inorganic materials Heterotrophic organisms are simpler than autotrophic organisms in that they contain fewer enzymes and specialized structures to carry out their metabolism Hence heterotrophic organisms would have been formed first

A mechanism by which heterotrophic organisms could acquire various synthetic abilities was proposed by N H Horowitz (1945) It has been found that the presence of an enzyme in an organism is often dependent on a single gene This is known as the one gene one enzyme hypothesis Suppose that the synthesis of A involves the steps

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where a b and c are the enzymes and A B and C are compounds which the organism cannot synthesize If the necessary compound A becomes exhausted from the environment then the organism must synthesize A in order to survive But it is extremely unlikely that there would be three simultaneous mutations to give the enzymes a b and c However a single mutation to give enzyme a would not be unlikely If compounds D C and B were in the environment when A was exhausted the organism with enzyme a could survive while the others would die out Similarly when compound B was exhausted enzyme b would arise by a single mutation and organisms without this enzyme would die out By continuing this process the various steps of a biosynthetic process could be developed the last enzyme in the sequence being developed first and the first enzyme last

Energy and biosynthetic processes It is necessary for all living organisms to have a source of energy to drive the biochemical reactions that synthesize the various structures of the organism The quantity that measures the available energy for a chemical reaction at constant temperature and pressure is termed the free energy (*see* FREE ENERGY) Animals obtain their free energy from *the oxidation of organic compounds by molecular* oxygen Plants and other photosynthetic organisms obtain their free energy from the energy of light There are also many microorganisms that obtain their free energy from fermentation reactions For example the lactic acid bacteria obtain their free energy from the reaction

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{Lactic acid}}{2CH_3CH(OH)COOH}$$

Yeasts also ferment glucose but they produce ethyl alcohol and CO_2 instead of lactic acid and there are bacteria which carry out many other types of fermentation reactions It is likely that organisms obtained their free energy from fermentation reactions until the supply of fermentable compound was exhausted At that point the development of photosynthetic organisms which obtain their free energy from light would become necessary The porphyrin substance chlorophyll seems to be necessary for all types of photosynthesis and would have had to be present in the environment or its biosynthesis developed in some way The first type of photosynthesis was probably similar to that of the sulfur bacteria and blue green algae which carry out the reactions

$$2H_2S + CO_2 \xrightarrow{\text{Light}} 2S + (H_2CO) + H_2O$$

$$\text{or}\quad H_2S + 2CO_2 + 2H_2O \xrightarrow{\text{Light}} H_2SO_4 + 2(H_2CO)$$

where (H CO) means carbon on the oxidation level of formaldehyde (carbohydrate) It is much easier to split H_2S than to split H_2O and so it would seem likely that organisms would develop photosynthesis with sulfur first When the H S and were exhausted it would become necessary to split water and evolve O the hydrogen being used for the reduction of CO *See* CHLOROPHYLL PHOTOSYNTHESIS

When the methane and ammonia of the primitive atmosphere had been converted to carbon dioxide and nitrogen by photochemical decomposition in the upper atmosphere water would be decomposed to oxygen and hydrogen The hydrogen would escape leaving the oxygen in the atmosphere and thereby resulting in oxidizing conditions on the earth It is likely however that most of the oxygen in the atmosphere was produced by the photosyn

tions of plants rather than by the photochemical splitting of water

Multicellular organisms The evolut on of multi cellular organism p obably occurred after the de vel pment of phot ynthesis The evolution of primitive m ltic ll la organisms to more complex types and the devel pment of sexual rep od ct on can be understood on the basis of the theory of evolution. S EVOLUTION ORGANIC [S L.M]

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Ligament

A strong fl ible c n cti ti s e band usually found bet een tw bo y p om ences Most liga ments are composed f de e fib o o necti e t s ue formed by par llel bundles f collage fibe s They ha e a h ing l ery appeara ce and are pliabl but o el sti This typ also m y f m part f a joint c p l o a art lar s rface un der synov l memb e uch a ociat d t n ... Bo E (BIOPHYSICS) CONNECTIVE TISSUE.

Another k d of l g m nt i omp sed e th ently r alm st nt r ly of yellow *elastic t ue* which is ext n ble The large l gam ntum nuchae at the ba k of th neck a d th ligaments between vertebrae are of this typ a d permit the b ding of neck nd trunk [E G ST]

Light

The term light, a c mmonly u ed refers to the kind f rad t electromagnet c ne gy that ... ated ith vi on. In a b o d en e light in c d the ent e ange of r d at o known the electrom gnetic pectrum Th b a ch of ence dealing with l ght, t o igi nd p pagat it effects, and the phe me a a s iated with t called *pt cs* Spe t scopy the bra ch f ... with t pert t the prod t on nd in tig ... f pect

... acceptabl theory f the n tu e f l ght mu t ... f om bserv t r ga d ng ts beh or ... c m ta s Th f e th rt le ... th a b ef a unt f the p i ip l f ts ... also t ble l ght i el d g th r l t on ... light t the lectr magn t c pe tr m a ... a d th n de tibe the app r t dual ... light. The m d *r of th t le d s-* ... *rou e* per m tal a d th o etcal n ... pert n nt t th tudy f th p bl m

PRINCIPAL FACTS REGARDING LIGHT

Finite velocity The fact that light travels at a finite peed or el c ty is well established both theo etic lly and e perimentally This speed is so high howe er a d the experime tal complexities of me suring it a e so great that th s is not a phen men n the a e age man c n check fo him elf The fi st succe ful measu eme t of the speed of l ght was mad 1676 by the Danish astronomer Ol R eme a d n e that t me nume ous in crea ngly precise xperim nts ha e been con ducted leadi g to th e rently accepted value of 299 792 8 km/sec n ac um I ound numbers the speed of light in vacu m r as may be aid to be 186 000 miles/ ec or 300 000 km/ ec

Diffraction and reflection On of the mo t ea ly b erved facts about light ts tendency t tra l t aight l es Caref l b erv tion hows howe er th t a l ght ray spread l ghtly whe pass g the edge f n bstacle This phen me n called diffract n The reflection of l ght s al o well kn wn The earth mo well as all other satell tes and pl ets in the solar y tem are ble nly by reflected l ght they ar t self lum us l ke th s Reflecti n f l ght from sm th opt al surfaces occ rs o that the angle f reflect n equals th angle of inc d e fact th t i most eadily ob erved with a pla m rror Wh n light re fl cted irregularly d diff sely the phenom n n is t rm d catter g The scatte g f light by ga pa ticles the atmosphere c u es the blue lor of th ky Whe h ge in f q ency (or w e *length) of the light* o s dur g c tte ing the scatt g is referr d to as the R m n effect

Refraction The typ f be d g of l ght ray call d ef acti caused by the fact th t light t a els at differe t pe d in d ff ent med — fast r fo exampl n air than in either gl s wate Refract on occur when l ght passes f om one med m into an the in whi h it mo at a differ t peed F miliar ex mple incl de the cha g n direct n of light ays a goi g th ough a pr m and th bent appe ran e of stick par tially mmersed n water

Interference and polarization In the phe me non call d interf nce rays f l ght em gi g from tw parall l lits c mb e on a s een to prod alternat g light and dark ba ds This eff t n be bt ned q ite ily in the labor tory d i bs rved i the c l r prod ced by a th film of o l n the fa of pool of water Pol rizat on of l ght s ually how w th P l oid d k S ch d k e qu te transp ent i d d ally Whe tw of them pla ed t gether how the d gree of t spa e cy f the omb ti n de p nd p n the l ti e t t n of the d ks It an b ed f m eady t a m ion of l ght to alm st tot l opa ty mply by tati g n d k with pect t the th

Chemical effects Whe l ght ab bed by rta bsta s h mic l ch ges t k pl e Th f i f rms th ba f r th e c of photo-

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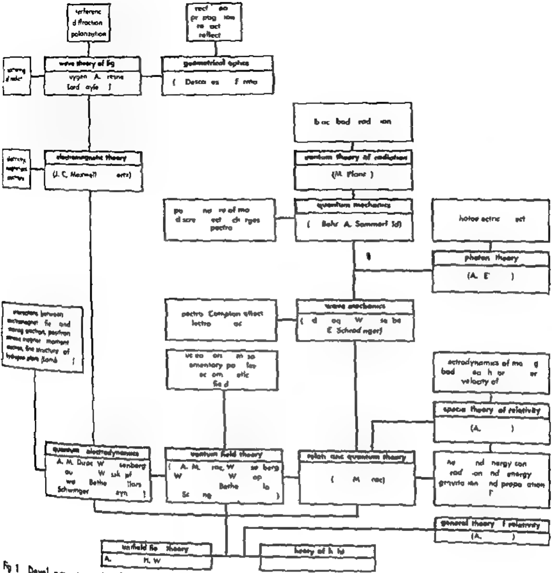

Fig 1 Devel pm ti th th ry f l ght (G W St k)

fead t] rr la ty b d mon trat d n ymbe f exp m nts The w e p t of th pect um of l ct mag et d t t at con n i gly h wn by th m l r ty of d f fraction p t e pr d ced o ph tog phi pl t ed tsomed ta b hi d dff a t g t g d t n f dffe t f q nc h a t a d bl l ght The s t rf e e ph m f l ght m reo ery m lar t s te ference f lects n ally prod ced m c w d es

P l nzat n dem tr te the tr e h of l ght w ve F rth t of f th ele tro- ma gnet ha t f l gl t f d n the p f d ng tra sp nt body th t ctra edl y be m f fl polar ed l ght th property l t l g th pl n f p l r zat f th t m wh n th l ody pla ed a m g et field Se FARADAY EFF CT

The f t th t th loc ty f l ght h d bee calcul ted f m lect d m g t c p m te (pe m tt ty d p rmeab l ty) was at the o t f Maxwell s clu n s 1865 th t l ght clud he t nd th r rad at n f a v s a d t b n e the fo m f w p p g ted c ding t lect magn t law Fi lly the b ers ti n that le tr ns and t o g e t diff t on patte n q t mil to tho p du ed by tbl l ght h m d t n s ry to sc ibe the wa e ha a ter to part cle S ELECTRON DIFFRACTION NEUTRON DIF R CTION

Velocity d t m tion The fi te el ity of t a m f s g l by mean f l ct ma et c wa a f ct well t bl hed f ll w e- l ngths f ad t n a r t f *terre trial* nd t om al p r ment A tro m l bserva t f o-c lled l p ing b tes l th al and pect o p t t k t nd c te that the eloc ty f l ght d ted by c d es n t d p nd n th loc ty f the e S B NARY STAR

M a em t f c f ll ba all t tw g o p (1) g p lo ty r gnal v l t d term na

chemistry Rapid progress has been made toward an understanding of photosynthesis the proce s by which plants produce relatively complex substances *such as sugars in the presence of sunlight This is* but one example of the all important response of plant and animal life to light

Electromagnetic spectrum The electromagnetic spectrum is a broad band of radiant energy which extends over a range of wavelengths running from trillionths of inches to hundreds of miles wave lengths of visible light *are measured in hundreds of* thousandths of an inch Arranged in order of in creasing wavelength the radiation comprising the electromagnetic spectrum is termed gamma rays x rays ultraviolet rays visible light infrared waves microwaves radio and TV waves and very long electromagnetic waves Detailed de criptions of these radiations are given separately *see* ELECTROMAGNETIC RADIATION and the articles listed therein *See also* ABSORPTION (ELECTROMAGNETIC RADIATION) DIFFRACTION INTERFERENCE OF WAVES OPTICS PHOTOCHEMISTRY PHOTOSYNTHESIS POLARIZED LIGHT RAMAN EFFECT REFLECTION (ELECTROMAGNETIC RADIATION) REFRACTION OF WAVES SCATTERING (ELECTROMAGNETIC RADIATION) SPECTROSCOPY

NATURE OF LIGHT

Early in the eighteenth century light was generally believed to consist of tiny particles Of the phenomena mentioned in the preceding section reflection refraction and the sharp shadows caused by the straight path of light were well known and the characteri tic of finite velocity was suspected All of these phenomena except refraction clearly could be expected of streams of particles and Sir Isaac Newton showed that refraction would occur if the velocity of light increa ed with the density of the medium through which it tra eled

This theory of the nature of light seemed to be completely upset however in the first half of the nineteenth century During that time Thomas Young studied the phenomena of interference and could see no way to account for them unless light were a wave motion Diffraction and polarization had al o been in estigated by that time Both were *easily understandable on the basis of a wave theory* of light and diffraction eliminated the harp hadow argument for particles Reflection and finite velocity were con istent with either picture The final blow to the particle theory eemed to have been struck in 1849 when the speed of light was measured in different media and found to ary in just the oppo ite manner to that a sumed by Newton Therefore in 1850 it eemed finally to be ttled that light consi ted of waves

Even then howe er there was the problem of the *medium in which* light waves tra eled All other kind of waves required a physical med um but light tra eled through a vacuum—fa ter in fact than through air or water The term ether wa pro po ed by Jame Clerk *Maxwell and his contempo* rarie a a name for the unknown medium but this scarcely olved the problem becau e no ethe ever actually found (*see* ETHER HYPOTHESIS) near the beginning of the twentieth century certain work on the emi ion and ab orpti energy that eemed to be under tandable o one assumed light to have a particle or corpu nature The external photoelectric effect th the emi ion of electrons from the surfaces of when light is incident on the surface wa these At that time then cience found it elf *uncomfortable position* of knowing a con ide number of experimental facts about light of some were understandable regardle s of wh light consisted of waves or particle other peared to make sense only if light were wav and still others seemed to require it to have a ticle nature

THEORY OF LIGHT

The study of light deals with ome of the fundamental propertie of the physical world is intimately linked with the study of the prop of submicroscopic particles on the one hand with the properties of the entire univer o other The creation of electromagnetic radi from matter and the creation of matter from r tion both of which have been achie ed prov fascinating insight into the unity of phy ic same is true of *the deflection of light beam* trong gravitational fields uch as the bendi starlight pa sing near the sun

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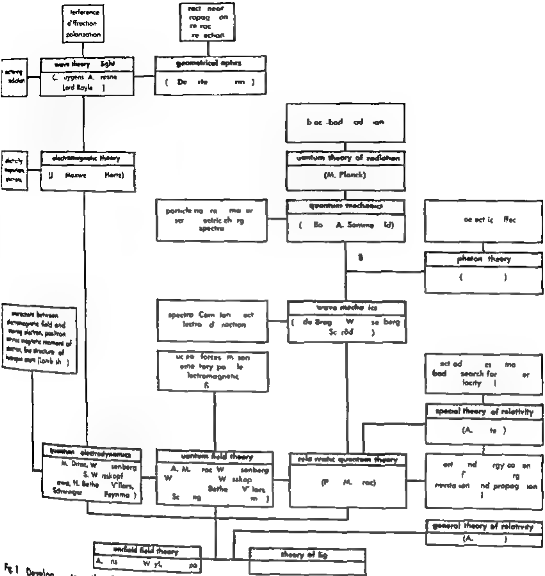

Fig.1 Develop ts th th ry f light (G W St k)

h a ent l m l ty b d mo t ted ı a
number of pe m ts The wa e pe t f the
entire spectrum f lect m gn tic r d at o is
t en gly h w by th s m l r tv f d f
ty pictures prod ced n a phot gr ph pl t
p red t m d ta e b hind a d ff t o g at g
h radiat f d ff t f eq en s ch s
d bl li ht The t fe ce ph m
f light m row very s m l r t ı t
re f elect n lly p od ed m w e d
n es.

Polarizat n d m tr tes the tr e h r
f light es F th p f f th lect
magnetic h t f l ght ı f d n th po
f nd g n a t p t b dy th t s
ed a be m f pl e-pol r ed l ght
propert f r t t ng the pl n f p l at
be m h th bod pl ed a m gn t c
Se F A D Y EFFECT

The f st th t th loc ty f light h d bee
calculated from lectr a d mag t p m t

(perm tt ty d p me bil ty) w s at the ot of
Ma well con l n ı 1865 th t l ght ı l d g
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t ele t m gn ti l w F ll the b erv t n
that le t n d ne t o a r e to diff
t on patt r q ıte s m la t th p d d by
ı ble l ght ha m d t n c ry t b w
h t t pa t l *Se* ELECTRON DIFFR CTION
NEUTRON DIF RACTION

V l city d t m t Th finite el ty f
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neti w fa t w ll e t bl h d f ll w
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a t om al e pe me ts A tr m l b rv
ti f o-called l psi b ries b th ı l nd
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f l ght d ted by d es t dep d th l
ty f th o S BINARY S ARS

M a m t of f ll ba ll nt tw g o p
(1) g p el ıty gnal l ıty dete m

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A classification of phenomena involving ligh according to their theoretical interpretation pro vides the clearest insight into the nature of light When a detailed accounting of experimental fact is required two groups of theories appear which *in the majority of cases account separately for th* wave and the corpuscular character of light Th quantum theories seem to obviate questions con cerning this dual character of light and make th classical wave theory and the simple corpuscula *theory appear as two very useful limiting theori* It happens that the wave theories of light can ope with a considerable part of the phenomena in volving electromagnetic radiation Geometrical optics based on the wave theory of light can solve many of the more common problems of the propaga tion of light such as refraction *provided that* the limitations of the underlying theory are not disre garded *See* OPTICS GEOMETRICAL

Phenomena involving light may be classed into three groups electromagnetic wave phenomena corpuscular or quantum phenomena and relativi effects The relativistic effects appear *to in*fluence similarly the observation of both corpuscu lar and wave phenomena *The major developments* in the theory of light closely parallel the rise of modern physics The developments *are charted* in Fig 1 and are discussed in the *remainder of* this article

Wave character of light Interference and dif fraction mentioned earlier are the most striking manifestations of the wave character of light Their

in also be hown that the p th betwe n any points in th sy tem is that which mi mize ime f r the light to tra l betwe n the points mat s principle) Th s p th would not be a ght line unless $i = 90$ or $i = r$

ell's l w states th t n in $= n$ sin where called th nd x f ef ct on of the med um llo s that the r fract e ndex of a medium i

r' becau e the r fractive index of a vacu m er c has the al l

upe sion The d per on $dn/d\lambda$ of a medium es.d be obtained fr m measureme ts f the a ti e index f d ff ent wa elength of l gh ; eight of exper m nt l e id nce ba ed on as- tonom al ob erv tio s is ag i t a di pe n in n Observat o of th l ght re ch ng the earth m the eclip ing b nary star Al ol 120 l ght years a.i (1 l ght y a $\sim 6 \times 10$ miles is the dis te tr d in acuum by a b am of l ht i ear) ho th t th l ght f all lo s s re- sed multaneou ly The ecl psi g occurs every h urs and 49 min Wer the e a diff e c of ve ty f r d light a d for blue light in i te tel ace as gr at a n part in 10 th s ta nid sh a m a ur ble time d ff en in the o rren of the eclips s i the e two of rs

Corpuscular nature of light In t i te a tion th matt r light ex hange nergy nly in di nt am unts c lled qu ta This fact is difficult reco ile with the id a th t l ght e gy i e d o t in a w e but easily sual ed i m f rpu le r photon of light

B k b dy (h at) d ation Th r d at on fr m m tt lly p rfe t heat d ator alled bla k des in l m th e chang f ne gy between t n a d m tte in a encl ed ca ity The b- ed frequ n y di tribu i n f the ad t on emitt d by the en l u e at a given t mp ratu e of the may n be orre tly described by theory only if e a umes th t light of freque y i absorbed m egral mult pl of a quant m of n rgy equal h where h i fu damental phy cal o stant led Pl nck co ta t The sta tl g d p rture m cla l phy ics w s made by M x Pla k l m the t e t eth c nt ry

Ph t l tric ff ct When a mono h m ti ram f e ct om gn tic rad at n llum n tes th e of a sol d (o l mmo ly a l qu d) ctron a e eject d f om th rf c r th phe menon k own as ph t em i n o the ext rnal b elect ic ffect The ki etic en g f the tr ns an be m a red el t i ally by m n f a collect r wh h neg t l h rged w th r ect to the em tt g s rf It is f und that th m f the photoele trons a they d mmed te nd ndepe d t of the ten i f th l ght beam even t ry l w l ght tions Th f ct ex ludes th p ib l ty f ac m l t n f en rgy f m the l ght b m unt l t rrespond g t the k net e rgy f th ted lect n h s been re hed The n mbe f ed be m Th loc t es f th elect n eje ted by light at arying frequenc s gree with the equa tion

$$\frac{1}{2} m v^2_{max} = h(\nu - \nu_0)$$

where m is the mas of the electron v_m the maxi mum ob erved el city the f equency of the il luminat ng light be m nd ν_0 a thr shold f quency charact i ic of th em tting ol d

In 1905 Albert Ein tei showed th t the photo- electric eff ct uld be a counted for by a uming that if the inc dent l ht is compo ed f photons of en rgy h p rt of thi energy h is u ed to ov re me the f ce h ld n$_0$ the elect on to the urfa e The e t of th energy appears as kinet ene gy of the jected electron

Compton effect Th e catter ng f r ys of fre- quency by the lighte elements au ed by the c ll i n f x ay photo s with ele tron Un d r ch i um tan s b th a atter d x ray photo t n nd a scatte ed el ctr n are ob erved a d the tte ed x ay ha a lo er frequency than the m m g x ray The k etic n rgy of the imping ng x r y the cattered r y and the att red el ctr n a w ll a th ir relat e d e tion a e in agreement w th alculati n m ol i th on s rvat o of e ergy nd moment m S COMPTON EFFECT HEAT RADIATION PHOTOELECTRICITY PHOTON

Quantum theories Th need fo reconcil ng M xwell th y f the el ct omagn ti fi ld whi h de c be the ele tr magnet c wa e hara te of l ght with the part cl n t r of ph t ns whi h d monstrates th equally imp rtant co pus ular h racte of li ht h ulted the formu lation of everal th tes wh h g a l ng way to- wa d g ng a at fact ry un fied tre tme t of th wa e and the co pu i la pi ture The e theorie n rp r te e ha d the theory of q antum el ct dyn m c fir t t f rth n rti l s by P A M D rac P Jo d W Heisenberg d W Pauli d on the the the earl er quantum me han s f L d Br gl Hei enberg and E S hr d g r Unr s l ed theor t c l d fficult es pe si t howe er n the higher than fi st appro i mati s f the t cti n b tween l ght nd ele mentary part le Th n orpor t on f a the ry of th nu leus nto a the ry of light s bound to call f r dd t n l fo mulat on

Di c s synthe f the wa e and o p cula theori s f l ght s ba ed n rewr ting Maxwell s equ t ns n Haml t i n f rm re embling the H m lt n an qu t ons of las l m ch s U ng th me formal m l ed in the t nsf m t of cl c l to wa e me ha l equati n by th t od t on f the q antum l a t n h D c bta ed n w eq t n f the l tromag t f ld Th luti f thi equat n r qui quant d w o r po d ng to ph t n Th p p tion f th n l i n rep nts th lect magn t field Th qua t z d wa s re ub- je t t H senb rg n t nty p in pl The q nt ed de cript n of d ti n c n t be t k n l t r lly t rm f e th r ph tons or w es but

tions using the relation c = distance/time and (2) phase velocity or wave velocity determinations using c = frequency/wavelength.

The group velocity is the average time for a light signal that is a modulated electromagnetic wave train to traverse a given distance (*see* GROUP VELOCITY). Romer's original determination of the velocity of light was based on careful observations of the time of eclipse of the moons of Jupiter from various points in the earth's orbit. Subsequent terrestrial determinations making use of revolving mirrors (J. L. Foucault and A. A. Michelson), a toothed wheel (H. L. Fizeau), or an electronically modulated light beam (E. Bergstrand) also measured the time required for light to traverse the distance between a source and a reflecting mirror. These are all group velocity measurements and furnish a value of c only if the experiments are carried out in a nondispersive medium in which the velocity is the same for all wavelengths. Otherwise the group velocity is smaller than the phase velocity by 0.007% (2.2 km/sec) in air, 1.5% in water and 2.4% in ordinary crown glass. *See* DISPERSION (RADIATION).

Determinations of the phase velocity, which is simply the speed of the wavefront (*see* PHASE VELOCITY), are indirect and make the assumption that $c = \lambda f$, where f is the frequency and λ the free space wavelength of the electromagnetic radiation. Most of the measurements of this type involve microwave interference in various forms: E. F. Florman with two sources, K. D. Froome in an apparatus similar to a Michelson interferometer, L. Essen, J. P. Gordon and H. M. Smith in a microwave resonance cavity. D. H. Rank and also E. K. Plyer determined c by calculation from microwave and infrared spectroscopic measurements of the ratio of cycles per second to waves per centimeter for a certain molecular rotation frequency. The phase velocity can also be calculated from the ratio of electromagnetic to electrostatic units. A detailed description of these experiments is found in the bibliographical references.

The measured magnitudes of the velocity of transmission and the phase velocity seem to be in reasonably good agreement among themselves, possibly to a few parts in 10^5. However, the experimental values determined by the two methods are at an admitted and disturbing variance with one another. The velocity of light is not as constant as it is sometimes thought to be. While according to the theory of special relativity the velocity of light will be the same in any frame of reference independent of its state of motion, this is true only for frames of the same gravitational potential. Conceivably local variations of the gravitational potential could lead to variations of the measured velocity of light, although experiments for detecting these variations remain to be devised. The effect of the gravitational potential at the sun's surface or at other points in the universe is quite appreciable compared with the precision of many measurements of c. *See* POTENTIALS (PHYSICS).

Electromagnetic wave propagation. Electromagnetic waves can be propagated through free space devoid of matter and fields and with a constant gravitational potential, through space with a varying gravitational potential, and through more or less absorbing material media, which may be solids, liquids, or gases. Radiation can be transmitted through wave guides with cylindrical, rectangular, or other boundaries, the insides of which can be either evacuated or filled with a dielectric medium. *See* WAVE GUIDE.

From electromagnetic theory, and especially from the well-known equations formulated by Maxwell, a plane wave disturbance of a single frequency f is propagated in the x direction with a phase velocity $v = \lambda f = \lambda\omega/2\pi$, where $\omega = 2\pi f$. The wave can be described by the equation $y = A \cos \omega(t - x/v)$. Two disturbances of same amplitude A, of respective angular frequencies ω_1 and ω_2 and of velocities v_1 and v_2, propagated in the same direction, yield the resulting disturbance y:

$$\begin{aligned} y &= y_1 + y_2 \\ &= 2A \cos \tfrac{1}{2}[(\Delta\omega)t - x\Delta(\omega/v)] \cos(\omega t - \omega x/v) \end{aligned}$$

Here $\Delta\omega = \omega_1 - \omega_2$ and $\omega = \tfrac{1}{2}(\omega_1 + \omega_2)$. The ratio $u = \Delta\omega/\Delta(\omega/v)$ is defined as the group velocity, just as the ratio $\omega/(\omega/v)$ is identical with the phase velocity. In the limit for small $\Delta\omega$, $u = d\omega/d(\omega/v)$. Noting that $\omega = 2\pi v/\lambda$, $d\omega = 2\pi(\lambda\, dv - v\, d\lambda)/\lambda^2$ and $d(\omega/v) = -2\pi\, d\lambda/\lambda^2$, an important relation between group and phase velocity is obtained:

$$u = v - \lambda\, dv/d\lambda$$

This shows that the group velocity u is different from the phase velocity v in a medium with dispersion $dv/d\lambda$. In vacuo $u = v = c$. With the help of Fourier theorems the preceding expression for u can be shown to apply to the propagation of a wave group of infinite length but with frequencies extending over a finite small domain. Furthermore, even if the wave train were emitted with an infinite length, modulation or "chopping" would result in a degrading of the monochromacity by introduction of new frequencies and hence in the appearance of a group velocity. Considerations of this nature are not trivial in measurements of the velocity of light but are quite fundamental to the conversion of instrumental readings to a value of c. Similar considerations apply to the incorporation of the effects of the medium and the boundaries involved in the experiments. Complications arise in the regions of anomalous dispersion (absorption regions), where the phase velocity can exceed c and $dv/d\lambda$ is positive. *See* MAXWELL'S EQUATIONS; WAVE EQUATION; WAVE MOTION.

Refractive index. A plane wave front, in going from a medium in which its phase velocity is v into a second medium where the velocity is v', changes direction at the interface. By geometry it can be shown that $\sin i/\sin r = v/v'$, where i and r are the angles which the light path forms with a normal to the interface in the two media.

ward g t lassic l elocity addit on theorem (uch as i n w k o do not pply to light) a elocity d ff re ce of 2 w ld b d tected u der such cum tan es

N t ly does the earth mo e in a b t arou d th sun, b t it i c ed with the n the ga ba rot ti t ward Cyg s with a l city of several h d ed f k l mete per s cond d the ga itself is m ng with a h gh speed its lo- cal spiral gr g Speed of hundr d and po bly tho ands f kil m te s per econd hould be de- te bl by m rem ts o a th in two rth o- al directi ass ming f our e that the e th motion it itself with espect t i rt al p ce or fixed th t s h a pace has the phy cal me ning scribed to t. The u pe ted r lt of the exp i nt as th t ch eloc ty d ff ence ould be detected, that s, o r lat m t o could be d tected b pt l mea

The M h lso Morl y ppar tu (Fig 3) n sts f a h rizont l Mi helson i terfe m t r th it tw arm at right ngle (see INTERFER OMETRY) Th m rr r ar adj st d that the n tral b t light f g f lls n the os ha of the serving t lesc pe Th s d ates qual ty f op- tical phase, nd the ef e an equal ty f the tim s taken b th light be m t tr el f m the be m ng rf t ea h of th tw m rr rs nd back. Rotat f the nt r sy t m by 90 i ded b an a gl s w ll s epet t o of th ex periment at n s t mes f the y r ll e f u d to leave the ce tral wh te l ght f ge d s ged In ge er tem nd pl c d d ting n change in th time q ired by the l ght t t rse th t arm f th i t f m ter wh n th i direct rel t e t th d e t f th e th motion ar red H d the e bee a d ffer c the loc t f l ght the tw d r t OM d OM' the t arm o ld b f u equal l gth the m t l adj tme t F x mpl f th l ght t eled f ter in the direct n OM (n the a g ge g in back and f rth) then the c rrespo d g arm would ha e to be lon r so a t make the time f travel equal in both rms If the app tus w e tur ed thr gh 90 the h rt arm would take the place f th lon er m a d the fa ter l ght would now t avel in the shorte rm a d the slower l ght in the longe arm a n ticeabl fring displ cem t would but a tually does n t t ke pl ce

E tein theory ccou ts for th n ll esult by the s mple e planat on that no rel ti m ti be twee the apparat and the ob rver e sts n the xper ment N cha ge in me ed le gth h oc c ed n e the direct on a d b au the pr pa gat n of l ght is t pic no v l city diff nce nor detect n f rel tive m tion ho ld b ex pect d

G a t it l a d eb l r d sh fts Two d ffer ent ki ds f h ft or d pla em t f pe t al lin s tow rd the red e d f the spe trum are b- erv d in p ctr g am take with tarl ght l ght f om nebul e O i the r b t ext emely g nific t gra tati al r d h ft or Ein tei hift whi h ha bee me red in m spect a f om white dwarf ta Th oth m h m w dely co ter d is the r d shift in pe t a f m neb l e u ally de bed as bei g c u d by a rad l Doppler effe t cha cte ing n pa si of the u erse"

The mo t f m s e mpl of th g a tat nal ed E ft th t ob erved in the p ct m of the o- lled d k c mpa n f S u Th i te e f th compa n w s p ed t d b F W B s l 1844 n the b s f a p rt bat n the mo- ti n f S b t beca e of ts we k l mi ty (1/360 th t f th un 1/11 000 th t of S u) t w n t b n d t l 1861 This mp i a whit dwa f of m s mp able t th t of the n (0 95) b t h ing el ti ly mall d s f 18 000 km d th fa t t lly h gh d n ty of 61 000 times th t f w te Th c mp ni n h w a h ft t pe t al l nes rel t e t th es em t t d by S s t lf the h ft of 0 3 A for the B lm β l f hydr g wa el ably det rm ed by W S Ad ms

The n b l red shift s syst mati h ft ob- rved i the pect a f ll b la b t m red w th th c l um H nd K b orpt n l s D t n f b l ar d term ed ph t metr lly b m m nt f th r t n tes d it i f nd th t th w el gth hift towa d th red i w th th d t n f the neb l e f m th e rth (The rth d t ha p i l g d p t f xp n f the i d d l ed th t p t m wh t l ke th t f a man a wd whi h d pe g—e y i d id l i th wd w ll fi d h m lf t n eve i c e s g d t f m f h n ighb) Th E g f w le gth w th d t ce h bee gi b F G H bbl

$$\Delta\lambda/\lambda = 1.7 \times 10^{-} d$$

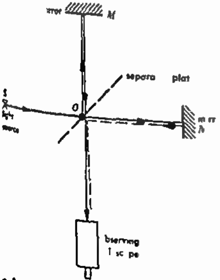

Fig 3 Michelson-Morl y pe m t

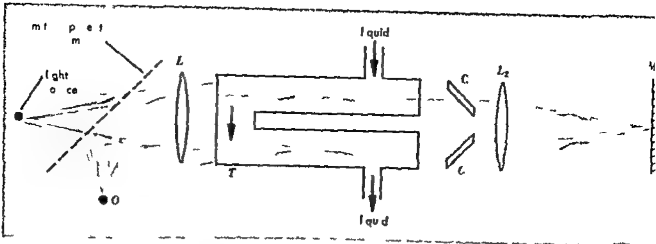

Fig 2 Fizeau's experiment C compensator plates M mirror L_1 L_2 lenses T tube O location of interference fringes

rather is a description of the probability of occurrence in a given region of a given interaction or observation See HAMILTON'S EQUATIONS OF MOTION QUANTUM ELECTRODYNAMICS QUANTUM FIELD THEORY QUANTUM MECHANICS QUANTUM THEORY NONRELATIVISTIC QUANTUM THEORY RELATIVISTIC UNCERTAINTY PRINCIPLE

Relativistic effects The measured magnitudes of such characteristics as wavelength and frequency velocity and the direction of the radiation in a light beam are affected by a relative motion of the source with respect to the observer occurring during the emission of the signal carrying electromagnetic wave trains (*see* DOPPLER EFFECT) A difference in gravitational potential also affects these quantities Several important observations of this nature are listed in this section followed by a discussion of several important results of general relativity theory involving light For extended discussions of both the special and the general theories of relativity *see* RELATIVITY

Velocity in moving media In 1818 A Fresnel suggested that it should be possible to determine the velocity of light in a moving medium for example to determine the velocity of a beam of light traversing a column of liquid of length d and of refractive index n flowing with a velocity v relative to the observer by measuring the optical thickness nd The experiment was carried out by Fizeau in a modified Rayleigh interferometer shown in Fig 2 by measuring the fringe displacement in O corresponding to the reversing of the direction of flow If v' is the phase velocity of light in the medium (deduced from the refractive index by the relation $v' = c/n$) it is found that the measured velocity v_m in the moving medium can be expressed as $v_m = v' + v(1 - 1/n^2)$ rather than $v_m = v' + v$ as would be the case with a Newtonian velocity addition

Aberration of light J Bradley discovered in 1725 a yearly variation in the angular position of stars the total variation being 41 sec of arc This effect is in addition to the well known parallax effect and was properly ascribed to the combination of the velocity of the earth in its orbit and the speed of light Bradley used the amplitude of the variation to arrive at a value of the velocity of light Sir George Airy compared the angle of aberration in a telescope before and after filling it with water and found contrary to his expectation that there was no difference in angle *See* ABERRATION OF LIGHT

Michelson Morley experiment The famous Michelson Morley experiment one of the most significant experiments of all time was performed in 1887 to measure the relative velocity of the earth through inertial space Inertial space is space in which Newton's laws of motion hold Dynamically an inertial frame of reference is one in which the observed accelerations are zero if no forces act A point in an orbit is the center of such a frame *See* FRAME OF REFERENCE

The rotation of the earth about its axis with tangential velocities never exceeding 0 5 km/sec is easily demonstrated mechanically (Foucault pendulum precession of gyroscopes) and optically (Michelson's rectangular interferometer) The surface of the earth is not an inertial frame In its orbit around the sun on the other hand the earth has translational velocities of the order of 30 km/sec but this motion cannot be detected by mechanical experiments because of its orbital nature *see* EARTH (ORBITAL MOTION) The hope existed however that optical experiments would permit the detection (and measurement) of the relative motion of the earth through inertial space by comparing the time of travel of two light beams one traveling in the direction of the translation through inertial space and the other at right angles to it The hope was based on the now disproven notion that the velocity of a light beam would be equal to the constant c only when measured with respect to the inertial space but would be measured as smaller $(c - v)$ or greater $(c + v)$ with respect to a reference frame such as the earth moving with a velocity v in inertial space if a light beam were projected respectively in the direction and in the opposite direction of translation of this frame

re cla i al theories that tt mpt to represent lectrom gnetism and gra t t a a pect of acetim g om try Alth h th re is some ex perim tal ev de c fo t between elec rom gn t m and gr t t th subject remain specul tive. F a d c s on of the bette known unificat n pr po al see UNIFIED FIELD THEORIES also SPACE TIME [G W ST]

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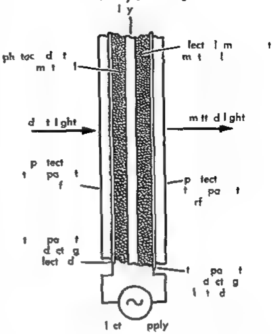
Light amplifier

An opt al electrical yst m th rep odu e a d l ght d ice e with a gr tly r ed br l iance.

On system empl ys m d fi d t le is cam tube called a im g rth up n wh ch th d l ghted sc n i f u d The mag rth n changes th im g f th sc n nt a e f electrical impul thr gh a ep ted c g procedure on the fa e of th t b These mp l then greatly ampl fi d d tran m tted t a n p ct tube whe e b ill nt ew f ngi l s d pl y d B htn ampl fi f the o d r f 40 000 ha b en ec m bed. S KI E.COPE TELEVISION CAMERA TUBE t m ba b e d t h t em d s provement of th im ge e ult f m t le- de in a t n my a d f m fl op b th med c l p f A mod ficat n the im ge orthi n t ma e t l d ctly nature t x y p rm t l m t n of th fl o rescent screen.

A ther light ampl y t m e mbi e th pho- condu ti ce phen m on d the le t l m scence phe men n s th t d mly l ghted e red n n de f thi mble p d ifferent imag f the th pp te rf LIGHT PANEL) Th nc d t urfa e f th is co po ed f a l ye f ph t ond ti erial h h h the p p rty f c nd t g b p p rt to the de ty f the r d ed upo t Wh e the l ght ad t a that the co d t n f l t rre t s gr t ed here the ad t l w th d ct on i

The trol m nes nt m t al h s th p p ty e gl ght wh r ltern t g l tr ed e t nsi t t s f If a lt h g appl ed t a r t the mb ed h wn in th illu t t n a f incident l ght n th phot c d t g mat l of th t t l ltag t b ppl d the lectrol m sc t m t r al th d



S mpl fi d k t h f a l ght mpl fi (t t l)

n a a f l w de ty n id t l ht At tho p t whe e th in de t l ht de ty elat ely h gh th phot d t e m teri l p des a g od lec t cal nd t o p th d ss nt lly the f ll lt g of th s pply i pl d a r the lect l m nes nt m t rial t th sp t (Th paq e h ld b twe n the l ver pe ce ly mall lt e dr p) C eq tly th s m te ial will m t high dens ty f l ght t th p t At the a of the i d t e whe the dent l ght de ty s l ti ly l w th ph t c nd ct mat al pro- ide a m h p er nd ti n p th nd b b l ger f t n f th t t l pply olt ge C seq ntly l lta s ppl ed t the lect o- l m t m ter l a d th den ty f em tt d l ht s l w t h s S ELECTROLUMINESCENCE PHOTOCONDUCTIVITY [W B B]

Light panel

A u f are l ght r th t empl y th pr ple f ele t lum sc e t p d c l ght L ht p el mp ed f tw h t f el tr lly co d m te l o a th n c d t g ba ki d th th r t p e t d ct film pl ed n pp te d f pl t c ce m h et m p e nted w th ph ph s zi c lfid a d m ll m nt f mp d f c pp ma g n Whe n lt t g ltag ppl d to th c d t e heet el t fi ld ppl d to the pho ph E ch t m th lect c fi ld h ge t d l dg el t f m th ed es f the ph ph ry t l A the lect f ll b k t th rm l t m t t th y ffe t th tom f th l ght mp t f oppe m es a d d t f th w l gth f l ght m tt d (ELECTROLUMINESCENCE)

where d is in parsecs (1 parsec = 3×10^{18} cm) Red shifts in nebulae up to $1\,1 \times 10^9$ light years distant have been measured in a comprehensive program carried out at the Mount Wilson Observatory by E G Hubble and M L Humason *See* EINSTEIN SHIFT RED SHIFT

Results of general relativity The propagation of light is influenced by gravitation This is one of the fundamental results of Einstein s general theory of relativity which has been subjected to experimental tests and found to be verified Three important results involving light need to be singled out

1 The velocity of light measured by the same magnitude c independently of the state of motion of the frame in which the measurement is being carried out depends on the gravitational potential Φ of the field in which it is being measured according to the equation

$$c = c_0\left(1 + \frac{\Phi}{c^2}\right)$$

Here $\Phi = -GM/R$ where G is the universal constant of gravitation ($6\,670 \times 10^{-8}$ cgs units) M the mass of the celestial body in grams R the radius of the body in centimeters and c_0 the velocity of light in a vacuum devoid of fields

For example the absolute value of the term Φ/c^2 is about 3000 times greater on the sun than on earth making the measurements of c smaller by two parts in 10 on the sun as compared to measurements on earth

2 The frequency of light emitted from a source in a gravitational field with the gravitational potential Φ is different from the frequency ν_0 emitted by an identical source (atomic nuclear molecular) in a field free region according to the equation

$$\nu = \nu_0\left(1 + \frac{\Phi}{c^2}\right)$$

Spectral lines in sunlight should be displaced toward the red by two parts in 10 when compared to light from terrestrial sources

3 Light rays are deflected when passing near a heavenly body according to the equation

$$\alpha = \frac{4GM}{c^2R}$$

where α is the angular deflection in radians and R the distance of the beam from the center of the heavenly body of mass M The deflection is directed so as to increase the apparent angular distance of a star from the center of the sun when starlight is passing near the edge of the sun The deflection according to this equation should be 1 75 sec of arc a value which compares favorably with eclipse measurements of the star field around the sun in 1931 The measurements *indicated values up to* 2 2 sec of arc when compared with photographs of the same field 6 months earlier This most en a tional prediction of Einstein s theory might seem le urpri ing today when the corpuscular photon character of light is widely known and when a Newtonian M/R^2 attraction might be considered to be involved in the motion of a corpu cle with the velocity c past the sun However application of Newton s law predicts a deviation only half as great as the reasonably well verified relativi tic prediction

Matter and radiation The po ibility of creating a pair of electrons—a positively charged one (positron) and a negatively charged one (negatron)—by a *rapidly varying electromagnetic field* (γ rays of high frequency) was predicted as a consequence of Dirac s wave equation for a free electron and has been experimentally verified I Curie and F Joliot as well as J Chadwick P M S Blackett G P Occhialini and others have compared the number of positrons and negatrons ejected by γ rays passing through a thin sheet of lead (and other materials) and have found them to be the same after accounting for two other groups of electrons also appearing in the experiment (photoelectrons and recoil electrons) Other examples of negatron positron pair production include the collision of two heavy particle a fa t electron passing through the field of a nucleus the direct collision of two electrons the collision of *two light quanta in vacuo and the action of a nu* clear field on a γ ray emitted by the nucleus involved in the action

Evidence of the creation of matter from radiation as well as that of radiation from matter substantiates Einstein s equation

$$E = mc^2$$

which was first expres ed in the following wc If a body [of mass m] gives off the energy the form of radiation its mass diminishes by $E/$

In regard to exchanges of energy and mon tum electromagnetic waves behave like a grou particles of energy

$$E = mc^2 = h\nu$$

and momentum $\quad p = h\nu/c = h/\lambda$

Finally many experiments with photons that they also possess an intrin ic angular mon tum as do particles Circularly polarized light example carries an experimentally ob ervable gular momentum and it can be shown that un certain circumstances an angular momentum be imparted to unpolarized or plane polarized li (plane wave pas ing through a finite circular ap ture) In any case the angular momentum will quantized in units of $h/2\pi$

The inverse process to the creation of electr pairs is the annihilation of a po itron and a ne tr n resulting in the producti n of two γ quanta (two quantum annihilati n) Nuclear ch reactions are known *to in ol e similar pr ce* *S e* CHAIN REACTION NUCLEAR ELEMENTARY PARTICLE INERTIA OF ENERGY PAIR PRODUCTION (ELECTRON POSITRON)

Unified field theories In conclu i n one mig m ti n the so-call d unified field theori The

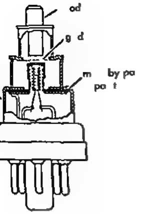


Fig. 1 Lighth se t b c t w y d w g (K R ... rg V cu m T b McG w H ll 1948)

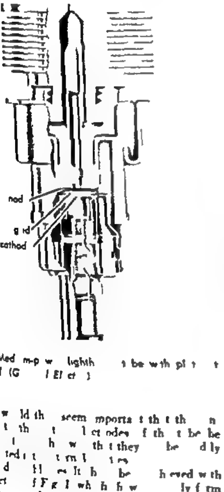


Fig. 2 Med m-p w lighth t be w th pl t t lerg nd (G l El ct)

... It w ld th seem mporta t th t th n ... t th t l ct odes f th t be be ... ght l h w th t they be d ly ... ted i t t rn l t es

These d ll es lt b be h eved w th ... t ct f F g l wh h h w ly f rm ... lighth t be Th t be t l a pl -eler ... fig t f th t port n f th ... lt k lt w th t t be pl gged i t ... ent ll t t r Th l ad ... th lo-f q ency t ent a d k wh h ... rrent fl w i f th most p rt d l Th ... ter lect od ty i also ed ed t ... m m.

A later fo m f tube i hown n Fig 2 In this t be the anode is t the ba e of the lighth e and th cath de is at the small diameter e d whi h i ju t oppo ite t the t tion in the pre i figure By th means the heat-di sipation capacity of the a de can be incre ed The t b shown u a ce ramic rather than gla cyl der between the di ks connected to the ele tr de This pr ides a metal cer m c l p whi h i naturally m re rugged th gla s Metal ceramic tubes are al capal le of p rating at h gher tempe t es nd the ef e have g te d p ti d p w pa t y f g

See Vacuum tube [K R S]

Lightning

The larg park l ht p od ced by an abrupt d t s di charg of el t c ty through th a r g lly de tu bulent co d t o of the at m phe e

C m l mbus clouds wh h produce l ghtni g t n tro gly i pw d m ng ai nd freque tly e t d t ltitude h he than 40 000 ft W thin th e cl d i s fact t to ca the ea t d ep rati f ele tri h rge Confli t ng theor es ha e l en p op d t e pl n th ele t fi ati H we er th y ll l e lo d a d pr p t t part l nd l d t e tually the me h ge d t b t The upp part of thunde t rm p ti ly harg d wh eas the c tral nd l w p rt re p edom ntly neg tive I m l ud afte ra h f rm d sm ll p it e h g ce t is f d th l w p rt f the l d

Whe l d l ct fi tio ha proceed d t the po t wh th p te t l gr die t betwe n adja ent h g enter or betw n the l d and gro d the b kd wn lu the large p rk c lled l ght g s A bt kd w pot nt l f bout 10 000 /cm been gge t d as n appro- p te l e f a r t ni g wat d plets

It h been establ h d that l ghtn tr ke t gr d i nt ted by a tep l d r A s rge f le t m es d wn w d abo t 50 m n bo t l μ ec d th n t p Aft p u e f pe h ps 50 μ th t p t k pl Th eq e ce r pe ted t l the le de hes the gr nd Wh n th oc u a rge f h m es rap dly p the p th tak ly th t p l der Wherea th a ag peed f th tep l d i f the ord of 10 m/sec th m n tr k mo e p th p i n zed p th t peed f th d r of 10 m/ ec Th l m os ty l th o-c lled eturn tr k i qu te t

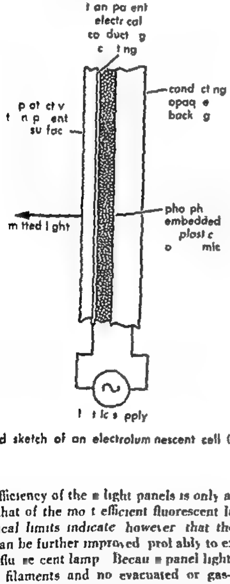
After n int rval of the o d r of 0 01 se an th r tr k u lly oc r th me chan l. These ec da y t rn t k e p ded by d wn ward m i g dart l d r wh h d ot show t p h t t A ma y 30–40 t okes h e bee be rv d t occ r i th ame han el

Cl d to-cl d t kes lso i l a tep l ad d m n et rn t k

Th rr t f th r t rn t kes i c es er g f bo t 6 i t a m mum al f

In contrast to incandescent vapor discharge and fluorescent lamps, which are essentially point or line sources of light, the electroluminescent light panel is essentially a surface source of light. Complete freedom of size and shape is a fascinating aspect of luminescent cells.

Brightness of the panel depends upon the voltage applied to the phosphor layer and upon the electrical frequency. In general, higher voltage and higher frequency both result in a brighter panel. Blue, green, red, or yellow light can be produced by the choice of phosphor, and the proper blend of these colors produces white light. Color can be varied for a particular phosphor by changing the frequency of the applied voltage. Increasing the frequency shifts the color toward the blue end of the spectrum.



Simplified sketch of an electroluminescent cell (not to scale)

The efficiency of these light panels is only a fraction of that of the most efficient fluorescent lamps. Theoretical limits indicate, however, that the efficiency can be further improved, probably to exceed that for fluorescent lamps. Because panel lights employ no filaments and no evacuated or gas-filled bulbs, replacement of units is virtually eliminated. Glareless uniform distribution of light from large area sources is possible without shades, louvers, or other control devices. See ILLUMINATION. [W B B]

Lighthouse

A distinctive structure built on or near a shore which exhibits a light of distinctive characteristic to serve as an aid to navigation. Lesser lights may be displayed from fixed structures called beacons or from floating buoys or lightships.

The characteristics of the lights displayed by lighthouses are given in light lists available to mariners and in abbreviated form on charts. Some lights have one or more sectors in which the light appears red, usually to warn of some danger in this sector. In other sectors most lights are white.

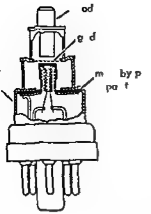
Lighthouse on a coastal headland (U.S. Coast Guard)

Lighthouses have been diverse in structure and type of light. Towers up to 200 ft were constructed along the Mediterranean coast of Egypt many centuries before Christ, with beacon fires maintained by priests. Logs, coal, oil, gas, and finally electricity have been used to provide lights. An attendant is continuously on duty at many lighthouses, but some are unattended and some recent installations are controlled remotely from a convenient location. See PILOTING. [A B M]

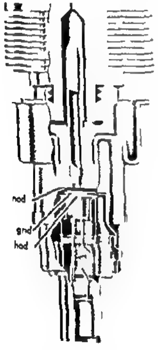
Bibliography: U.S. Coast Guard, *Aids to Navigational Manual*, CG 222, 1950; N. Bowditch, *American Practical Navigator*, U.S. Navy Hydrographic Office, H.O. 9, 1958.

Lighthouse tube

A special type of triode developed to operate at very high frequencies. A limitation of conventional tubes for operation at high frequencies occurs because of considerable circuit impedance associated with the wire leads that are attached to the electrodes. These wires individually have considerable self-inductance, and there is also considerable stray capacity between them. In addition, the most efficient circuits for operation at the ultrahigh frequencies are cavities rather than lumped cir-



Fg 1 Lghth se t b t w y d w g (K R Spannenb g V m T b M G w-H ll 1948)



Fg 2. Med m-p w lighth t b w th pl t t large nd. (G I El t)

ent It ld th n eem import t that th co nection t th a l el ctrodes f th tube be brought t h wa that th y c n b e dly incorpor ted t xte l t es

These des abl res lts h e b ch e d w th th struct f F g l h h sh w an ea ly f rm Lighth se t be Th t be ut l ze a pl ne lec trod fig at n f th acti portn n f th d t ent c ax l l ne t t r Th le d ad nt ages ar ed ed becau th d t the r d of equency t d k wh h current fl w i f the m t p rt r d l Th e lectrod ap ty is l d ed to a m.

A late form of tube hown in F g ll In this tube the anode m t the ba e of th lighthou e and th cath de is at the m ll d amet r end whi h i ju t opp ite to th situ t on n the prev us figu e By this mea s th heat di pation capac ty f the an de c n b incr ed Th tube hown u a ce ram c r ther than glass yl der between th di k connect d to the lectrodes Th s p ovide a metal ce am c e elope wh ch s naturally m e r g ed th n gl ss Metal cerami tube ar l o pable of ope ti at h ghe temperature and ther for ha a gre ter d ip ti and power capactiy f r a g e siz *See* VACUU I TUBE [K R S]

Lightning

The l rg spa k l ght p od ced by an abrupt di c ntinuous d ch rge of le tri ity through the gen lly u der turb lent c nd t ns of the at m pher

Cumul imbus lo ds wh ch p d ce l ghtn g t n tr ngly upward mov n ai nd frequently e te d t alt t de hi h r tha 40 000 ft With n th e lo d ri us fact r ct to u e tl e rea t n and separ ti of el ctr c ch rge Co flicti g the es ha been prop d t e pla n the electri ficat o II we er they ll n l e cl ud and p e c pit t o p rti le nd le d to e e t ally the s me cha ge d t b t n The uppe p rt f th d r m rm a e po t ely ha g d whe ea the e tral d lowe pa ts ar p ed m nantly neg ti e In ome lo d aft r ai h f rm d a mall po it e harge e ter i f nd i the lower p t of the l d

Wh cl ud el ctrifi ati n h p o eeded t the p i t wh e the pot nt l grad e t between adja e t charg c nte o b twee the l d and gr und r che the b e kdow al n th l ge spa k c ll d l ght o u A b eakd wn potent al f abo t 10 000 ll /cm h s been s g ted as n app o- pr at l fo a o tai n w te d plet

It ha b n t bl h d th t l ght g t oke t g d ti ted by a tep l ade A f ele t s mo e d wnw d abo t 50 m in about 1 μ d th n top Aft pa e of p h ps 50 μ e other st p take pla e Thi eque e i r peated u til th lead r a hes the gro nd Whe th o u s g f h ge m es p dly up the path t ken by th st p l ade Whe ea the a e a pe d f th t p le d t f the rde f 10 m/ e the ma t oke mo e p th p e n ed p th t a pe d of the d r f 10 m/ ec Th l m ity of th o- alled etu t k s qu te i te e

Afte i terv l f the rder f 0 01 ec an th r t ok lly c urs n th s m ch nnel These c d r etum tr ke r p e ed d by down w rd m g d rt le d r wh ch d not how st p har t r t A ma y as 30–40 t ok h been b erved t ur i th m h nel

Cl d to- l d tr k al o m l e tep l ad d ma turn t ke.

Th r t the t rn trokes i re es n an a e ge l abo t 6 μ t m im m al fre-

quently exceeding 30 000 amp but sometimes as high as 200 000 amp It decreases to about one half the maximum value in an average of about 24 μsec Average currents during the strokes are of the order of 10 000 amp and about 500 amp may flow through the ionized channel in the interval between strokes A reasonable estimate of the diameter of the channel appears to be about 10 cm The high currents lead to thunder and are mainly responsible for the damage caused by lightning

See ATMOSPHERIC ELECTRICITY CLOUD PHYSICS TERRESTRIAL ELECTRICITY THUNDERSTORM

[L J B]

Lightning and surge protection

Means of protecting electrical systems buildings and other property from lightning and other high voltage surges

The destructive effects of natural lightning are well known Studies of lightning and means of either preventing its striking an object or passing the stroke harmlessly to ground have been going on since the days when Franklin first established that lightning is electricity (*see* ATMOSPHERIC ELECTRICITY LIGHTNING) From these studies two conclusions emerge (1) lightning will not strike an object if it is placed in a grounded metal cage and (2) lightning tends to strike in general the highest objects on the horizon

Fig 1 Installation of lightning rods on a home

One practical approximation of the grounded metal cage is the well known lightning rod or mast (Fig 1) The effectiveness of this device is evaluated on the cone of protection principle The protected area is the space enclosed by a cone having the mast top as the apex of the cone and tapering out to the base Laboratory tests and field experience have shown that if the radius of the base of the cone is equal to the height of the mast equipment inside this cone will rarely be struck A radius equal to twice the height of the mast gives a cone of *shielding* within which a hit will occasionally occur The cone of protection principle is illustrated in Fig 2 *See* LIGHTNING ROD

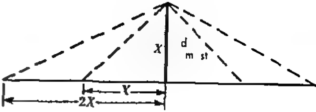


Fig 2 Cone of protection of a lightning rod or mast

A building which stands alone like the Empire State in New York City is struck many times by lightning during a season It is protected with a mast and the strokes are passed harmlessly to ground It is interesting to note however that lightning has been observed to strike part way down the side of this building (Fig 3) This shows that lightning does not always follow the paths prescribed for it by man but will occasionally dodge the protective devices provided

The probability that a building will be struck by lightning is considerably less if the building is located in a valley Therefore electric transmission lines which must cross mountain ranges usually will be routed through the gaps to avoid the direct exposure of the ridges

Overhead lines of electric power companies are *vulnerable to lightning* Lightning appears on these lines as a transient voltage which if of sufficient magnitude will either flash over or puncture the weakest point in the system insulation

Fig 3 A multiple lightning stroke to Empire State Building and nearby building Aug [illegible] 1936 B single continuing lightning stroke to Empire State Building Aug 24 1936

Many of the troubles that cause service i ter ruptio s on electr cal systems a e the res lt of flashovers of in lation. N perm n nt damage h s been done at the po nt of f lt, and ervice an be restored as soon as the c use of th trouble has disappeared. A puncture f the insulatio on the other hand, requires rep ir wo k and damaged apparat s mu t be removed f om serv e.

Th re are a numbe of p tecti d v ce to l m t or preve t l ght ing d mag in ele tric power sy tem a d equipment. Th w rd p tecti e s u ed to conn te ithe ne or tw f ncti th p even tion of tro bl n the l m ati n of t after t oc cur. Various p otect e mea h e been devi ed eith r to p event l ghtn ng f om e tering the y tem or t d ipate it h rmle ly if it d e.

Overhead ground wires and lightning rods These devices are used to prevent lightn ng from striking th lectric l ystem.

The gro ded m tal-cage prin ple app ached by overhead gr und wi es, pref rably tw n talled over the t a mis n pha condu tor and grounded at h towe The gro nd wir must be pr perly located with re pect to the ph e con

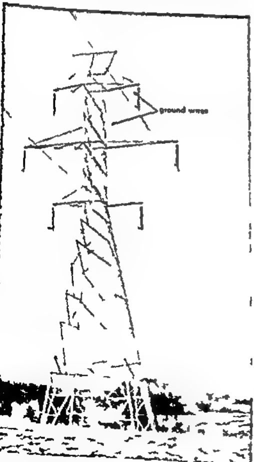


Fig 4 Do ble-c suspe ion ow the Olive-Gooding G ow 345-k tr sm io l ne w h tw cuits ng nd w th tw ground wi s. (I drawn nd Michig Ele c C Ame ico Electric P w C .)

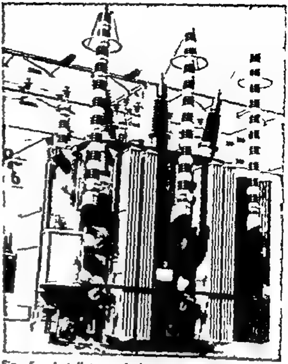


Fig 5 l toll t of th Ge l El ll Co Thy t t ton-cl ss e t t d 121 kv l ne-to-g o d p ot ct g 115-k d f 20 000 kv th ee-ph se p we t o f rm

du t r nd h dequate cle rance f m them both at the tow and through ut the sp n If towe footing res t nces e too high they must be l w red t ac ptable al es with dri n gr u d ods with bu d counte po es The lightning stroke curre t m t ha e a s ffic tl low imped anc p th to gro nd so that the ltag alo g this path t h gh e gh to fla h back to the l ne ndu t rs (F g 4)

Th gr u d wir s are ften brought in o the t rmin l ub tations F add ti n l shi ld g of the s b tat n l ghtn ng rods r i talled Sev e al d r ally u ed to obta n the de ed p o-tect n.

Lightning arresters These prot tive de-es f edu ing the t n ent y tem rvoltag s t lev ls c mp t ble with the term l ppa tus n ul tion They con ected i pa allel with the pp tus t be pr te ted One nd f the rrest s ground d a d also b ded t the e of the equ pm nt be ng p otected th other end is nected t the lectric condu t r (Fig 5)

V l e-type arrest rs p de a lati ely low d s-ha g path t gro d f the tr n ient erv lt age and a rel t ely high res ta e t th p we y tem f ll w rr nt so th t the perat n does n t use a sy t m h rt c t

In sel t g rrester to p tect a tr n forme f r ampl th ltage levels that a be m t i ed b th reste both on swit h ng urges nd l ght g u ges m t be coordinated with the with t d t gth f th tra sf rmer t thes urges Arrest g p park-o r v ltages d scha g lt

ages on various magnitudes of discharge currents *arrester lead lengths and other factors must all be* evaluated *See* LIGHTNING ARRESTER

Rod gaps These also are devices for limiting the magnitude of the transient overvoltages They usually are formed of two ½-in square rods one of which is grounded and the other connected to the line conductor They have no inherent arc *quenching ability and every operation is usually* associated with ■ system outage

These devices are applied on the principle that if an occasional flashover is to occur in a station it is best to predetermine the point of flashover so that it will be away from any apparatus that might otherwise be damaged by the attendant short cir *cuit current*

The flashover characteristics of rod gaps are such that they turn up much faster on steep wave-front surges than the withstand voltage character istics of apparatus with the result that if a gap is set to give a reasonable margin of protection on slow wave front surges there may be little or no *protection for steep wave front surges Also* the gap characteristics may be adversely affected by weather

Rod gaps will limit transient overvoltages They have no inherent arc quenching ability and once becoming conducting they continue to arc until the system voltage is removed Since each operation is a system outage they should not be considered an arrester

Immediate reclosure This is a practice for re storing service after the trouble occurs by immedi ately reclosing automatically the line power circuit breakers after they have been tripped by a hort circuit The protective devices involved are the power circuit breaker and the fault detecting and reclosing relays

This practice ■ successful because the majority of the short circuits on overhead lines are the re sult of flashovers of insulators and there i no per manent damage at the point of fault The fault may be either line to ground or between phases Reclos ing relays are available to reenergize the line only once or three times with adjustable time intervals between reclosures

If the relays go through the full eq ience of reclo ing and the fault has not cleared they lock out If the fault has leared after a recl sure the relays return to normal

Permanent faults must alway be l cated and re moved from a *system and the a cepted electric* protective devices are p wer circuit breaker and suitable protective relays *See* CIRCUIT TESTING ELECTRICAL ELECTRIC PROTECTIVE DEVICES

[E M H]

Bibliography American In titute of Electrical Engineers *Revised Report on Standards for Valve and Expulsion Type Lightning Arresters* AIEE 28B 1956 E Beck *Lightning Protection for Elec tric Systems* 1954 W W Lewis *The Protection of Transmission Systems Against Lightning* 1950

Lightning arrester

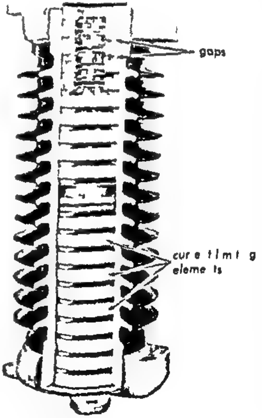
A protective device designed primarily for connec tion bet een a conductor of an electrical sy tem and ground to limit the magnitude of tran ient overvoltages on equipment

The valve arre ter con ists of a single gap or multiple gaps ■ eries with a current limiting ele *ment* The gaps between paced electrodes prevent the flow of current through the arre ter except when the voltage acro s them exceed the critical gap flashover They reseal when the voltage returns to normal The current limiting (valve) element re duces the current flowing through the arre ter and aids the gaps to re eal

The current limiting element is a nonlinear re sistor who e resistance decrea es sub tantially ■ the voltage across it increa es

Other types of arre ters called expul ion ar resters have spaced electrodes in an interrupting chamber which contains gas evolving material

System overvoltages may be of either external or *internal origin that i lightning or sy itching The* arrester is unable to determine the origin of the overvoltage and mu t attempt to limit the magni tude of all abnormal voltages above the gap park over voltage Hence a lightning arre ter is really a voltage surge arrester



Thr e k (gap spa k lt ge) Thy te m g l t t -cla s l ght g a rest r ted 60 kv d cha g oltage Cut-away ect o h w mag et gap struc tu betwe ■ paced lect odes a d cu e t l m ti g l m ■ (Ge al El ct i Co)

I portant appl c t on characteri t cs of ar m ers a e (1) gap sp rkover (n rmal f equen y a d im l e) (2) gap re eal volta e (maximum perm ble rmal f eq e cy olt g ac os the reste) (3) d ch ge lt a ro the arr t r (al type) du ng pa age of rr nt, and (4) d ha g apabil ty

The gap spa ko er oltage and the d scha ge lt g h r cte t c det rmine the maximum tr t ltag le el perm tted by the arreste They a e the meas res by whi h the protecti e ef fi ency of arrest s d term n d The d cha ge apabil ty s th m a u e of the ar e t r end an e k w el ht g nd sw t hi g rge

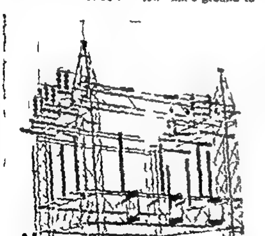
Arrest rs a e l fied a tati ntermed ate or d trib t n Stat n-cla arreste a e al e arrester ed for the p ote t n of apparatus n import nt ub t ti wh re th m t effi ie t pro tection s desired I term d ate l r te s als l et pe a used for the pr te ti n f ppar t m m ll a d med m ub tation wh e o- a m n d r tion d not ju t fy the u f t u n type ar e t a D tr b t n cla a re t r may be ther l pul i n arre t rs nd ar u ed f the p tecti n f p le type d tribut on ppa r t lly d str but n tran formers

[E M H]

Bibl o phy Am r ca Sta dard As oc t on Ligh g A re t s fo Alt nating Cu t Powe Cir uits ASA Sta dard C62 1 1957

Lightning rod

A met ll c rod set up on an xp d levat on f stru t nd on ected t low hm c ground to



Ou door b on H dso R wn p mpi g s ion in Ch lsea N w Y k Light i g od a lo- ated on he four hed m f h eal truct

intercept and t pr ide a direct c nd ct ng path to gr und f r li htn ng di harg s that might other w se damage the st uctu e be ng p otected Light n ng rod a e al o called lightning ma t

The ffecti ene s of the protecti n obtain d de pen ls upon (1) s ffic nt l e ght of the u term nal end of the r d f the lightn ng stroke to ter minat on it rath r than n the p otected t t t (2) suffic ent c d cto (rod) cr ss ecti n to ca ry th li htning tr ke curr nt t gr und and (3) a low re ta ce g ound onn cti n S e LIGHTNING AND SURGE PROTECTION

[E M H]

Light year

A unit of mea u em nt of ast onomi al di tance A l ght yea is the d stanc l gl t tr vels in 1 s de- e l y a O e l ght year is eq i alent to 9 461 × 10 kil m te s or 5 879 × 10 m l s D ta ces to me of th ne r r el stial objects mea u ed in u ts of l gl t t me a e sh wn n the tabl

Obj t	D t from Ea th (l gl t t m)
Moo (m)	1 3 sec
Su (m)	8 3 m n
M rs (losest)	3 1 m
J p t (losest)	33 mi
Pl t (losest)	5 3 h rs
N rest ta (Proxim Ce t)	4 3 y rs

Th un t wh le u eful fo ts g phi p ta ti f th n rm u ale f tell d t c m eld m u d t chn cally S e ASTRONOMICAL UNIT PARALLAX (ASTRONOMY) PARSEC.

[J L CR]

Lignite

Th nam of th t g oup f c n olidated l gnitic c al with a heat v l e le than 8300 Btu/lb on a m t m ne al m tter free b sis Unc ol dated l gn t oal a e alled b wn co ls ex ept n Eu r p wh r all l gn t c als a de g ated a brown coal The brown coals f G rm ny wh they re p rti ul ly imp tant, ha e l e cl fi d a soft a d ha d The s ft b own o l a e cl s fi d a rthy d f l a eo the hard a d ll (m tt) d bright (glance) c al Th gl nce br wn coals r bl k l g co p nd t b b t m n al f cla s C. S e COAL.

O er 9 f l gn te n the U ted St t n the n rth e tr l tate p c p lly in No th d South Dak ta d Wy m ng in the F t Un n (Paleoc) fo mat n All l ut a fract n of 1 f th r m nd i in T xa The tot l erve s n the ord 463 × 10 t n Th ma n u f lig t n the Un t d States i comb ti n f r th p d t n f heat and pow Lign te u d t any gr at di tan f om th p nt f r g no m lly eq d hydrat o and b quet g M n g u ually l y ope t o t pp g m th od

[C H C]

Lignumvitae

A tree *Guaiacum sanctum* also known as holywood lignumvitae *which is cultivated* to some extent in southern California and tropical Florida Lignum vitae is native in the Florida keys Bahamas West *Indies* and *Central* and *South America* It is an evergreen tree of medium size with abruptly pinnate leaves The tree yields a resin or gum known as gum guaiac or resin of guaiac which is used in medicine The very heavy black heartwood is used in bowling balls blocks and pulleys and parts of instruments Other species include *G coulteri G guatemalense* and *G officinale See* FOREST AND FORESTRY TREE [A H G]

Liliales

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Limburgite

A dark glass rich igneous rock with abundant large crystals (phenocrysts) of olivine and pyroxene and with little or no feldspar

The glass is brown and usually alkali rich Phenocrysts are well formed and the pyroxene shows zonal structure (diopsidic cores and titanium rich margins) Small quantities of feldspathoid hornblende and biotite may be present Granules of titanium iron oxide are abundant and widespread

Limburgite is a rare rock and forms lava flows and small intrusive bodies (dikes sills and plugs) It is associated with basanite and alkali basaltic rocks It probably originates from basaltic magmas and lavas by accumulation of olivine and pyroxene *crystals under the influence of gravity* Thus limburgite may grade through oceanite to basalt *See* BASALT IGNEOUS ROCKS [C A CA]

Lime (botanical)

An acid citrus fruit *Citrus aurantifolia* usually grown in tropical regions because of its low cold resistance The two principal groups of limes are the West Indian or Mexican and the Tahiti The West Indian lime is a small tree with irregular branches having short stiff sharp spines The fruit is small (walnut sized) and strongly acid It is more sensitive to cold than the Tahiti lime which is a more vigorous tree bearing fruits of lemon size

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A general term for the various products of calcined limestone for example quicklime and hydrated lime Principal uses of lime are in mortar *stucco and plaster for the building industry* as a flux in the metallurgical industry as a refractory for lining open hearth furnaces as addition to soils *either for agricultural purpose or to stabilize* roadbeds as a chemical raw material as in the production of glass and also in water purification sewage treatment *pulp and paper production*

suga refi ing, petr le m refini g and t nning

Limest es a e cla fied a rding to the r mag e um conte t h h-calci m lime t nes have less than 5 by e ght (% wt) magnes m carbonate and magnesia limest nes ha e er 5% wt when the sto e co tains bet een 30 and 45% wt mag es m carbonate it is k own a dol m tic lime-st ne Dolom te tself is m eral of mixed calcium and magnes m carbonate rr spond g to the formula CaMg(CO) r ab ut 46% wt MgCO Th high-e lcium nd d lomiti lime tones are the importa t sou ces of lime the esulting l mes re co espondin ly amed

Limest e (CaCO) is alc ed in vertical shaft kl t drive ff th ca bon di xid th resulting product, qu kl me b ng mad up of cal ium x d (CaO) w th s me magne um ox d (MgO) Qu klim is u ed a u h but oft n t is treated th te t f rm hydrated l me Ca(OH) The p oces f hyd at on i kn wn a laking but g n rall the term l ked lime is used t designate the material w th x ess wate th t n eded t form the h dr x d Hydr ted lim i dry powde sl ked l me a paste o putty M lk-of l m is hy d a ed l m su pe s o nd ol t on n wate

H d a l c l me is mad from a l mest ne on ta n g l a and al m na wh h wh n th tone s cal ined t a t mpe atur just hort of f on f rm anh d ated calcium alum num l ates wh ch al low th materi l to set u der water *See* PORTLA D CEME T

H h-c l m hyd ated l mes c n t t lly of $Ca(OH)_2$ but d l m t l mes hyd ated n the orm l f h n (t atmo ph ric pr re) ntain co ide bl amount of unhydr ted MgO Be e of tro bles au ed b th dela d hydr t n f th m terı l (f r exampl popping f pl ster m d w th d l m t l m) it h b me the pr t e to p od c a peci lly hyd ated d l m t c l m by h d at g u der pres u

Th phy l p perti f l me e affe ted by th co d t f le n t n nd hydr t on Fo ex mpl d adb rned d l m te i a c e-gra ned high-tempe t e p od t w th l w rat f hyd tion, a d t i f l efr t ry *Se* FER TILIZER KI N LI IESTONE PLASTE [t c M]

Limestone

A sed ment ry rock mpo ed d min tl f r ba at m r l p n p lly bo tes f c l m d m g esi m Limest es a th mo t b d t f th l t ock M h k wledge f r rt f r t p leo t l g d seq e tly of the ea l i f l i d rth h t ry comes from th fos l ta ed i them Alth gh th w d lime-t n sed n th g r l se e bo e pec fi c ll t f t rbo t ock d m nated by the m l l t CaCO a pposed t d l m t a t m f a bonat rock d m ted b th *m n al* d l m i $CaMg(CO_3)_2$ Alth gh the *m n ral* g l ompos t n f most l mest es i m l th r t at es t f r they m be f rmed n d a g t ety f en d tion *S* DOL MITE ROCK

Chemical composition The hemic l compo tion of limestones is l rgely calcium oxide CaO and c rbon dioxide CO Magnesium ox de MgO i a common con tituent and if it e ceeds 1 or 2% the rock m y be termed magne ian limestone Sm ll amount f ilica and alum na may al o be present these are due t the presence of cla u mate ial qu rtz, and clay Iron ox de m y b p ese t either as arb nat (der te ferr an dol omite) or in other mineral h as clay Stron tium (Sr) may be pre ent a an import nt trace element, probably d i ed f om or g nal fossil ma terials n whi h it was in orpor ted into aragon te form of CaCO

Mineralogy The chi f mine ls f limest nes are alc te nd ar g nite and n th d lomitic lime-tone d l mite. Calc te and a agon te ha e the ame c mpos t on but b au their tru tures are different, arag ite is un table with refe ence to alc te in earth urf ce en ir nment and will b tran f rmed int the latt r with t me E en though ar gon te s unstable it f rm as a p e ipitate from a water both in rg n c lly as ool tes and biogenically through the intermediate mech ni m of b ologic l se et n by hell form ng rg n ms. The co of agonite to calc te is ec m pl hed in a elat ely sh rt time j st a few yea s f r ome f sils Ancient rocks alw y ont in al cite rather than g nite

Dol m t altho gh t seem t be stabl in earth su fa e environments i f rm d as a primary p ec p t te only unde pecial ndit ons su h as high alinity or high alk l n ty Petrograph c evi de ce gge ts that mo t d l mite i formed post dep s ti ally by the inter ti n of magnesium i n ini t rst t al waters w th alc t

S d r te the i on carbon te i found in *ome* limest nes, but iron occur in carbonate form ch efly as ferr an-dolom te S l ca may be *present,* ther fi ly d em n t d th ughout the *rock o* greg ted int n d les of ch rt. Silica al occurs a mall cry tal th t have gr wn in place duri g diag nes Feld p r occur *in the same way but i* les common than l Oth r min r ls found in limest es are gla c te coll phane and pyr te A h t f oth min *als may be* f u d as mall mount of l stic mat ri l brought in by current includ ng alm t alw y a sm ll m u t of fine-gr i ed clay Orga ic *matter* may also b f u d *Se* DIAGENESIS

Textures *Th* text res of lim t nes eveal much abo t the *o gin Th* hief t xtur l l m nts in a great many l mest nes are fo il wh l or fr g me tal The species r presented are a gu d to th ec logy nd n onme t f the ite of d posi t l dd tion, th natur of th fo il deb is wheth r complet art ulated hells o fragments in all tages f d arti lat n nd fragm tat n is g id to th presenc of *bott m* urrents that may h t ansported the fo il fr m place to pl ce on the bott m

Som mechan lly depos ted l mestones show w ll sorted p rt les f c lcite cem nted by cl ar

Lignumvitae

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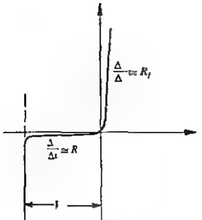


Fig. 1 V lt ge-c rr t ch ct t f j d d

current ch te t f typ l s m du t diod h n i F 1 In the fi t qu dra t th character t c i th t f th f rw d b ased d de Here th h t tic may be pp mated by a linea es ta f a l w l Thi alue m ght range from a f w hm f m j t n d od t sever l h d ed ohm fo a typical cuum t b diod In th th d q d ant r b as r g n the chara teri t c m y be pp im t d by x tre l l ge lin re t e t l the dd n le k t th ct ty f V o e r At th po nt known th Ze br kd w lt g th rr t becomes t llv depend t f It e (SEMICONDUCTOR) Eith th sh p tra t n that we h g g fr m th e-to-f rwa d b condition r th Ze e eg m y b d f l m ting

Th se f both cha ct ti m ltaneo ly is illustrated in F g 2 The p t mpl tud f th tput wa fo m is lim ted pp mat ly at the fe nce ltag V and th n g ti e mplit de s l mited t a l el $V - V_B$ a e pond t the b kd wn volt ge f magn t de V_B Sh p l m ting in th forward b s d ction s a h eved when the forward ist R_f m ll compared t the e ver e-b re tance R wh n R_f sm ll c m p red t R a d wh any sh nting l ad tanc R l rge mp d t R_f

Th ac m d d may b used a l m ter u ing the forw rd r e b reg o but t has no u ful e kdown m l to the Zene egion f the ju ct n di d If ther p t e o ati e l miting eq d ther va uum micond to d des m y be u d with th refe en olt d the d de p l ty d If b d rection l l m ti des ed the cir u t of F 3 may be u ed w th tw d de nd two p ate b as It a

M lt l ment le tron t b or t a t r al may be u ed l mite s G d c t l m t g of um tub s sh wn Fig 4 N rmally when ed n ampl fi the g d t e with e sp t t the th de nd th put es stan h h If th gr d b c m p it e w th p t t the th de g d re t flow nd the inp t re ist n is l w In th s p t, the gr d c th d c cu t f the tub b h es as uum d de w th th w f rm lim ted h wn The pl te c cu t t s t ampl fi t on p p t d th mpli fie pl t ltage w f m f the no l m ted p r t m t d h wn

Th t ti n ch t t f th tp t ci t of p t d a m tube o a comm n m t t t n t r m v al b u d t bt n limit g The t f h de ce a d the tput ch t ti wh ch m y b ppl d t th de e h w n Fig 5 F th p nt de the f mily of

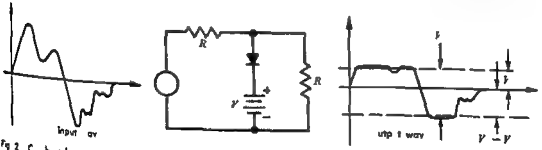


Fig 2 C b ed se-b d Z b kd w l m t g

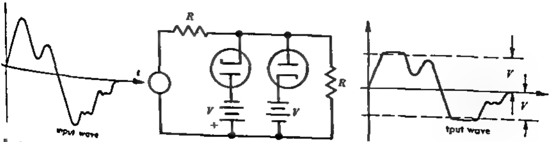


Fig 3 B d ctional l m g g tw d od

intergranular calcite. If the particles are sand size the rock is termed calcarenite. In general the mechanically deposited limestones show the same kinds of sedimentary structures as do clastic rocks. Cross-bedding, stratification, current lineation, and even graded bedding may be displayed. Oolitic and pisolitic textures are most abundant in limestones. *See* OOLITE AND PISOLITE.

Secondary textural features that are found in limestones include stylolites (cross-cutting veinlets filled with calcite) and replacement effects (typically that of rhombohedron of dolomite replacing calcite). Because the carbonate minerals are relatively soluble in aqueous solutions and because of the transformation of aragonite to calcite and calcite to dolomite, recrystallization and other diagenetic effects are particularly common in limestones. *See* STYLOLITES.

Classification. Limestones are divided into two major groups, the autochthonous and allochthonous. The autochthonous limestones have been formed in place by organic or biogenic precipitation from the water of the environment, usually sea water; the allochthonous have been transported from the site of original precipitation, the depositional agent primarily responsible being current action. The total distance of transport of allochthonous particles may not be great; the transportation is mainly a process of moving a chemical precipitate from one part of a sedimentary basin to another. Carbonate minerals of sand or finer sizes are rarely found in surface streams and rivers, for they are too soluble in water to persist for any distance.

Autochthonous limestones. Primary agents in the formation of autochthonous limestones are the lime-secreting organisms. Most important of these are the calcareous algae such as *Lithothamnion* and *Halimeda*, two forms that make up the major part of reef limestones. Foraminifera also contribute large quantities of carbonate. Other groups of carbonate-rock-forming invertebrates are mollusks, echinoderms (in particular the crinoids), and corals. Although many reefs are termed coral reefs, quantitatively the corals play a secondary role in carbonate accumulation. *See* ALGAE, FOSSILS.

The most common autochthonous limestone has been called normal marine limestone. Although whole fossils or parts of them are plentiful, the bulk of the rock may not be recognizable as fossil debris. Much of the now unrecognizable material probably came from calcareous algae or other biogenic carbonate that may have been broken up into very small particles by the action of bottom-dwelling scavengers. Inorganic precipitation may account for some of the fine-grained calcite. The rock is light-colored and normally has moderately well-developed bedding. Dolomitization is common, as are chert nodules.

Some limestones formed by the accumulation of organic structures may be either autochthonous or allochthonous. Among the varieties included in this group are (1) biohermal limestones, (2) biostromal limestones, and (3) pelagic limestones.

(1) Biohermal limestones are reefs or reeflike mounds of carbonate that accumulated in much the same fashion as the modern reefs and atolls of the Pacific Ocean. The mounds may range from a few feet up to several thousand feet in diameter and hundreds of feet thick. Some of the best described fossil reefs are those of the Silurian System in Illinois, Indiana, and Wisconsin. The central core of the reef is fossiliferous, dolomitized, and massive. It grades radially outward into sparsely fossiliferous, well-bedded reef flank strata that commonly dip away from the core. Farther away from the core the reef flank beds grade into fine-grained, well-bedded, relatively unfossiliferous normal carbonate inter-reef sediment. *See* BIOHERM.

(2) Biostromal limestones are biogenic carbonate accumulations that are laterally uniform in thickness, in contrast to the moundlike nature of bioherms. The fossils may be of many different kinds or they may be dominated by a single group. Particularly common are crinoidal and algal biostromes. The algal biostromes may show very few recognizable fossils, but stromatolites and algal laminations are common. Many of the biostromes are of mixed autochthonous and allochthonous origin, for some of the fossil debris shows evidence of transport. *See* BIOSTROME; STROMATOLITE.

(3) Pelagic limestones are formed from the accumulation of the limy parts of pelagic or floating organisms such as foraminifera. The resulting limestones are fine-grained and contain very few fossils of bottom-dwelling faunas. Since the foraminifera are chiefly responsible for pelagic limestone and the lime-secreting pelagic foraminifera did not evolve until the Cretaceous, pelagic limestones are restricted to Cretaceous and later systems. *See* FORAMINIFERA, FOSSILS.

Allochthonous limestones. The allochthonous or transported limestones show clastic textures typical of detrital rocks. The clastic particles may be of fossils, as in coquina or coquinoid limestone, of inorganically precipitated carbonate particles, as in oolite, or of earlier deposited limestone.

See CALCARENITE; CHALK; COQUINA; MARL; SEDIMENTARY ROCKS; SEDIMENTATION (GEOLOGY); TRAVERTINE; TUFA. [R.S.]

Bibliography. L. Cayeux, *Les Roches Sédimentaires de France, Roches Carbonatées*, 1935.

Limiter circuit

An electronic circuit used to prevent the amplitude of an electrical waveform from exceeding a desired level while preserving the shape of the waveform at lower than the specified level. Such limiters may be used to prevent the excursion of a waveform from exceeding a specified level in either the positive- or negative-going direction, or in both simultaneously.

Limiting is usually accomplished by making use of the nonlinear voltage-current relationship in an electronic device. A semiconductor or vacuum diode used as a clamp (see CLAMPING CIRCUIT) is often the key element in a limiter circuit. The voltag

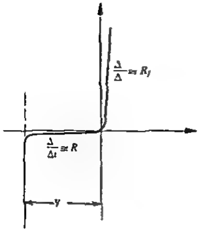


Fig 1 V lt ge-curr t ch ct r f j ct diod

current cha teri t of typ al semi nd ct diode s h wn i Fig 1 I the fi t q dr t th haracterist i th t f the f rwa d b a ed d ode Here the har t t c m y be ppr imated by a E ar es tan e f l w v l Th al e m ght r g from few hms f om ju ti d odes t several h d ed hm fo a typ l ac m t be diod I the th d qu d a t r er e b a reg the ch cte t may be appr imated by m tremel larg l ear res ta c u til the dd n b eak in the vi inity f V oc ur At th point, known the Ze br kd w oltag the c rre t becomes ev ent ll i depe d nt of ltage (e SEMI O DUCTOR) E the the sh rp tr sit on that curs h g g f om th reve to-f rw rd bia condition or the Zen r egi n m y be sed f lim ting.

The u f both h t ri t cs s m lta eo ly s illustrated in F g 2. The p s ti e mpl t de of the tput was f m is l mited app oximat ly at th r fer e oltage V a d the n g ti e mplit de i lim ted at a level V $- V_R$ c rr pondi g to th b e kdown ltage f mag tu le V_R Sharp l miting in the f rward l a d rect n i h eved wl n th f rward res tance R_f i m ll comp red t the re er bia re tance R wl en R_f i mall c m pared t R a d when any hunti g l ad resi tan e R_2 is la ge c mpared t R_f

The vacuum d ode m y be ed a l m t r us-ing the f rward re er e bias r g on l ut it has no usef l breakd wn imilar to the Ze r regi n of the ju tion diode If either po iti negati e limiting i req ired e ther uum r emic duc tor d ode may b used with tl e r feren oltage a d th diode pol ity rever ed If bid r ct al limiting i des ed the c cuit f F g 3 may be ed with two d odes d tw sep rate l lt ages

M lti l ment electr n t bes or tr n i t rs al o may be u ed a l mite s G d-c r ent lim ting f a cuum tube i h wn F g 4 N rm lly wh n sed an mpl fier the g d neg ti w th r pect t the thode a d th input res t n e i h gh If the grid bec mes p ti e with respect t th cathode gr d c re t fl w a d th input re i t ce i l w In thi respect the g d-cathode ir cuit f the tub bel es a a um d ode w th th wa f rm lim ted s h wn The pl t circuit r t m it ampl ficat n p pe ties and the mpli fier plate- lt ge w ef m f the nl m ted por ti i i e ted h wn

Th at rat n ch r ter ti of th o tp t c r u t f a pe tode v c m tube or a mm -em t ter tra t m y also be d to bt n limit ng Th cu t of a h dev ce nd th o tput harac t r t c whi h may be ppl ed t e th device h wn in Fig 5 F r the pe tod the family f

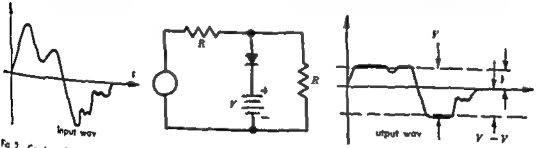
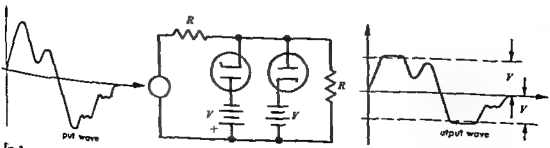


Fig 2 Co b d se bio d Z b kd wn l mit g



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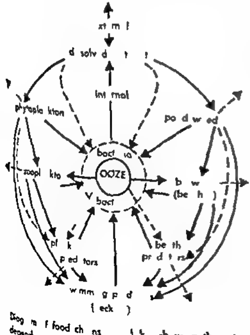
ndition for prod ct ty Lakes with poor phy i al n dit f the prod t n of organ ms a d uth l n trient le ls are k wn as lig trophic kes. Lakes w th e cellent phy ical c ditions f r he producti n of orga i m and w th high nutrie t evels are kn wn eutrophic lakes Lakes tend t ecome m re prod ct e thro gh the acti ties f her g ni ms, ps ing from oligotrophic t eu ro hi types.

Factors influencing productivity The primary act rs eces ry f the prod ctio of aquatic or anism are nl ght and certain inorganic and or anic substances d sol ed i th water or co ained in the a soc ted bottom material These b tan es in l d the d ol ed e m t im ortant of h ch ar oxyg n a d carbon d xide nd ino d sol ed sol ds such a compo nds of nitrogen, phosphorus and other elem nts all f hich ha e interrel ted hem cal r cti n The mo dary facto f body of water controll ng the elocity and lim ting the prod cti n of aquatic life e th shape area, ari us d mensions bott m types, temper tures, c rrents, t bid ty amo nt nd d pth f l ght penetr t n a d ther phy cal conditions.

Food cycles The aqu tic rg n ms devel p fro the sam h m l n tr e ts tho e that up port terrestrial rg ms Th h ic o ga i ms re h plants h h u the r w nut ient ub ta ces nd support th animals by c mplicated food chains. Definite cy les are mai ta ned between the organism and th nutrients the hemi al elem b g con erted into li i g org ni ms wh ch d and decompose b k into the ga c a d in rg n c u trients. The whole p oces is b ed o the ph to-yntheti cti ty f all aquatic pl ni utilizi g solar energy received l y rad ti n and is c ntr lled by the v rious physical fa t r Th tran fer l energy can be traced thro gh the ariou levels of the food chain



Diag m f food ch ns l k sh w g th depend f g m B k l d p ct th energy path ys d sol d lim th food so rc

Gen al habit ts f organ ms Th e aq atic or ganisms are gr uped int var us categ ries ac rd ing to where they li e The mo t o t ta ding group are the micr c pic plants and animal l ing sus pended in the open water the pla kton the organ i m li g in or the bott m the benth o the larger fr e sw mm g nim l the ekt n and the rooted plants or p nd weed l ing i the h ll w water

Zo ati n in aq atic hab tats Standing wat r re d vided i to zones a c rd ng t the condit n for l fe The littoral z ne i the h ll w area lim ted by the depth of s ff nt l ght pe etr tion f r g wth of rooted pl nts Th l mnet c zone i the pe wa te beyo d the l ttoral zone and i i hab ted by pla kt n a d e me n kto The pr f nd l zone ex i ts bel w the l mnetic zone in waters deep enough to develop temper ture strat f cati wh ch f r part f the y ar restrict the l we waters from c r u lating w th the ppe wat Runni g waters are di ided mainly int z nes cr ated by ondit of curre t and by rel ted bott m types w ft water (rap ds) z nes a d lugg h w ter (pool) z es ea h with ch ra ter tic orga ms. *Se* ECOLOGY FRESH WATER ECOSYSTEM LAKE MARINE ECOSYS-TEM OCEANOGRAPHY PHOTOSYNTHESIS [S E]

Bibliog aphy G E H tch nson *A T eatise n L m ol gy* I 1 1957 R L. Li dema Se sonal food-cycl dynamic i a enesc nt lake *Am Mid land Natu alist* 26(3) 636–673 1941 F ll tt er *Fund mentals of Limn logy* 1953 P S Wel h *Lim ology* 2d ed 1952.

Limonite

A n tu l amorph s- pp a ng material c n ti t t ng n part the materi l kn wn a br wn ir n e Lim ite occu s n m mmillary stala titic, nd e rthy mas es The ha d es i 5–5.5 (Mohs scale) a d the pe ific gravity is 3.6–4 The l t r itreo s nd the l r da l brown t bla Lim n te s essent ally FeO(OH) nH O b t w th dmixed h mat te lay a d ma es des X y n lys s h h wn that m h f the mat i l f rmerly th ught to be l m nite s goeth t L mo ll f rm by the o d ti n of p e x t g r mi e al d occu s with goeth t It i th pig me ll g m t al in y llow ls and mixed w th fi e lays k wn y llow che S GOETHITE IRON (EXTRACTION FROM ORE) ORE AND MINERAL DEPOSITS [C.S HU]

Limpet

Any f ever l pecies f the Class Ga tropoda phyl m M llu a h r cteri ed b a nical t t lik h ll Two famil es a g ner lly re gn ed the A m d w thout an pe i g at th apex f th h ll d the Fi s u llidae which ha ith r a small pe ng at th ap of th shell or ne

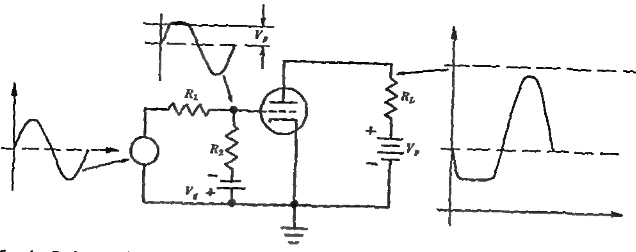


Fig 4 Grid-current limiting

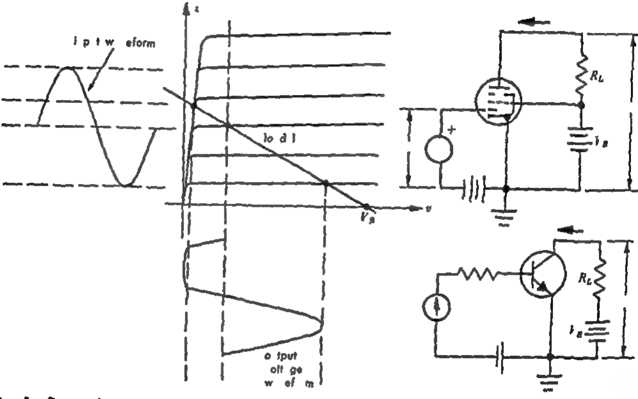


Fig 5 Output circuit saturation limiting

curves represents plate current as a function of plate voltage for various values of grid voltage for the transistor they are collector current as a function of collector voltage for values of base current (see PENTODE VACUUM TRANSISTOR CONNECTION) Either *n p n* or *p n p* transistors may be used according to the desired polarity of the output waveform The graphical construction shows the input output transfer characteristic as determined by the input signal swing and the value of the load resistance R_L The output is limited by the saturation characteristic

The term *limiter* is often defined in sufficiently broad terms to include the related operation of clipping (see CLIPPING CIRCUIT) which also results in the deletion of a portion of a waveform Limiters and clippers are often used together particularly where both negative and positive peaks of a resultant waveform are to be removed rather than bidirectional limiter used alone

For other wave shaping circuits see WAVE SHAPING CIRCUITS [G M C]

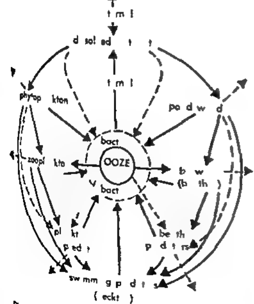
Limnology

The science of the life and conditions for life in lakes ponds and streams It involves the study of the physical and chemical conditions of bodies of water and the production of all organisms subject to these conditions The ultimate result of these studies is the determination of the productivity in terms of the amounts and kinds of aquatic organisms Limnological studies are of importance to any activity involving the use of bodies of fresh water such as the management of fisheries water supplies pollution sewage reservoirs and impoundment Bodies of water are classified according to their

d ns f prod ti ity Lakes with poo phy i al co d t s for the product n of ga i m and with l tr e t levels are kn wn as l g trophic lakes Lakes w th excelle t phys c l co dition for th prod ction f o g i m and w th high nutrient levels are known as eutrophic lakes Lakes te d t become m e p od ct e through the a ti t es of t r gani m ps. i g from ligotrophic to eu trophi types.

Factors influencing productivity The primary facto neces ry for th p oducti of aquatic or gn ms are s nl ght a d certa n inorgani and or ganic sub tances d ssol ed i the water r c n tained in the oc ted bott m material These substa ces incl d the d ol d ga es m t im portant of wh ch are ox gen and carbon d oxide a d aro d sol ed solids uch as compounds f trogen, ph ph ru and other elements all of hich h e interrel ted chem cal reacti s The seco dary factors of a body of water controlling the loc ty a d lim ti g the p od ctio of aquatic l fe th hape a ea, a o s d men ns bottom types, temper tures c rr ts t rbidity am unt and depth f light penetr tio a d other phy ical nditi

Food cycles The aqu tic rg ni m d elop from th sam h mi al n trients as tho e that up port t rrestri l rga i m The basic org ni ms are th plants whi h u e th r w n t ie t s b ta ces and support th nimal by c mplicated food chains. Definite y les a e m nt i ed between the organ ms a d th utrients th chem cal eleme t be g co erted int l ng o g ni ms wh ch d e a d decompose back into the rga c nd i g ic u trients. Th wh le p ocess is b ed o the ph to-



Di gra f food h depend f g ms. B k l d pct th n gy p th oy d sol d l th food

sy thetic acti ty of all aqu tic pla ts utilizing solar energy recei ed l y radi ti n and i c ntr lled by the vari us phy cal fa t rs The transfer f energy can be traced through the ari u levels of the food chai

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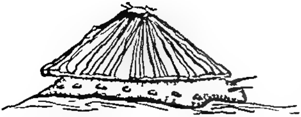


The limpet Patella sp., length to 2 in.

marked by a slit or notch along the margin. The surface of the shell in the latter family is usually strongly ribbed.

Limpets are utilized for food to a limited extent in Europe and to a much lesser degree in the United States. They are also utilized as fish bait and their shells are frequently used as ornaments.

Most limpets are small animals, 2 in. or less in length. Except for shell and foot shape they are essentially like other snails in their anatomy (*see* SNAIL).

Their choice of food is varied, as many limpets are highly specific in their diet. Some scrape algae from rocks, others eat organic detritus, some feed on a single species of seaweed, and at least one eats only eelgrass.

Most limpets have separate sexes and discharge their sperm and eggs into the sea. Some species are known to be functional as males when young but change into females when 2 or 3 years old. Limpets live a surprisingly long time for small invertebrate animals. There is one record of a Japanese species known to live for 17 years; others live at least 10–15 years.

Limpets have a strong homing instinct, spending virtually their entire life at a precise place on a rock, leaving the spot only to feed. The shape of the shell of many limpets conforms to the contour of the spot where they live.

The white cap limpet is a common Pacific Coast form about 1 in. long. The shell has a smooth white surface, but it does not have an opening at the apex. The rough keyhole limpet, also a common Pacific Coast form, is characteristic of the family Fissurellidae, with an opening at the apex of the cone and the shell marked with strong ridges. Its color varies from dark purple to gray brown. The keyhole limpet of the Atlantic Coast is a similar warm-water species ranging from Florida southward. It is white to buff in color. Several other species occur along both coasts. *See* GASTROPODA.

[J.D.R.]

Line

In axiomatic geometry a line frequently is taken as a primitive (undefined) concept, an element in line geometry, a class of points in a geometry with point as element, whose essential properties are stated as axioms. In analytic geometry a line is identified with (or is the graph of) a linear equation $Ax + By + C = 0$ with A, $B \neq 0$, 0 in cartesian coordinates (x, y). As a derived concept line is defined in terms of primitive notions such as distance or betweenness. For example, a line L is a set of points in one-to-one correspondence with the set of real numbers such that if points p, q of L correspond to numbers x, y, respectively, then distance $(pq) = |x - y|$; or if p, q are points, the line $L(pq)$ is the set of points consisting of p, q and all points x such that one of the points p, q, x is between the other two. *See* ANALYTIC GEOMETRY; GEOMETRY, EUCLIDEAN; PLANE; POINT.

[L.M.BL.]

Line integral

The line integral of a vector function **F** of position over a path C is

$$\int_C \mathbf{F} \cdot d\mathbf{r} = \int_C F_x(x,y,z)\, dx + \int_C F_y(x,y,z)\, dy + \int_C F_z(x,y,z)\, dz$$

where F_x, F_y, F_z are the scalar components of **F** along the coordinate axes. The path C is supposed to be a curve, smooth at least in part, defined parametrically by equations of the form

$$x = x(p) \qquad y = y(p) \qquad z = z(p)$$

for each smooth portion. The function $F_x(x,y,z)$, etc., must be defined at all points of C. When this is so, the line integral can be evaluated by writing

$$\int_C \mathbf{F} \cdot d\mathbf{r} = \int_{p_1}^{p_2} F_x(p)x'(p)\, dp + \int_{p_1}^{p_2} F_y(p)y'(p)\, dp + \int_{p_1}^{p_2} F_z(p)z'(p)\, dp$$

where the prime means differentiation with respect to the parameter and p_1, p_2 are values of the parameter at the end points of the path C or of a smooth piece. The integral has been converted into an ordinary definite integral.

When C is a closed curve, the line integral is called a circuit integral and is written

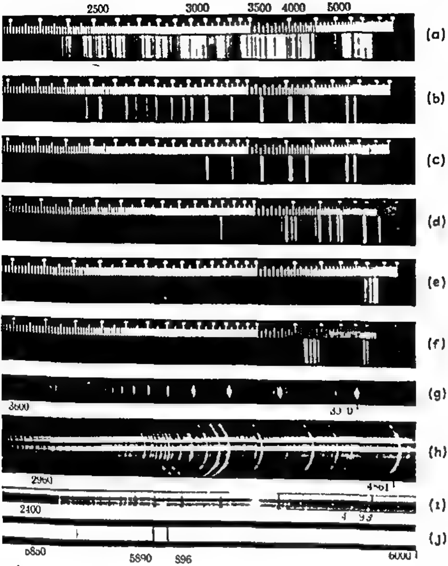
$$\oint \mathbf{F} \cdot d\mathbf{r}$$

Some physical applications of the line integral follow. If **F** is a force, the line integral is the work done in moving a mass along the curve C. If **F** is the velocity of flow of a fluid, the line integral is the circulation of the fluid along the curve. If **F** is the electrostatic field strength, the integral is the electric potential difference between the end points of the curve. If **F** is the electric field strength of an electromagnetic field, the circuit integral is the electromotive force of the circuit. In each example $d\mathbf{r}$ is physically a length. *See* INTEGRATION.

[M.H.H.]

Line spectrum

A discontinuous spectrum characteristic of excited atoms, ions, or molecules in the gaseous phase at low pressure. If an electric arc or spark between metallic electrodes is viewed through a spectroscope, the light source is seen in all colors characteristic of the metal atoms or ions. In order to avoid overlapping of these spectral images, th



Ph tog ph f mm l p ct w l gth g g t m m p t ( ) t (f) ll t k th th sam q rtz p ct g ph ( ) Sp t m f lro (b) M ry p ct m f m l d h q rtz. ( ) S m f m l d gl (d) Hel m a gl d h g t b ( ) N i gl d ch g tub (f) A g gl d h g t b (g) Balm f hydrog th lt l t grat g p ct m (h) Em p ct m f m g ch m ph f th S g t g pect m t k h t lt t th t t mm d t ly p d g tot l l p wh th t f th d by th M d k Tw t g st m g H d K I f t m h w m k d p ml el d f l m p Oth t g l d by hy d g d h l m () L b pt o p ct m f d m th lt l t t k w th g t g B ght l b kg d o th h b l ght t b rpt b y d th e l m t (j) S l p ct m i th ghb h od f od m D l s. Th D l (5890 A d 5896 A) b d by d m p th h m ph d to g th t t t th fl t m mb f th h w () (F m F A J k d H E Wh t F d m t l f Opt 3d d McG w H ll 1957)

pect osc p ded w th ry narr w l t wh h ll m ted by th l ght c a d th pectrum th rr y of b ght l m g of th l t d k b kgr d L p t a d ot cc t lly b t lt f m s f rt fi l l l ght e—th l t—bec t g es th l t c f f l pp g m g S ATOMIC STRUCTU A D CT SP CT O CO Y [W F M]

Linear accelerator

A part le eler t r wh h a lerat el t n p t n h a y s m tra ght l e by th t n f alt rnat g lt ge It h b en uc e sful ele at g l tr n t el c tie ry ea that f l ght F a e t ded d us e PAR TICLE ACCELERATOR [W K H P]

Linear energy transfer (biology)

A physical factor which is significant in biology because in many biological actions of high energy radiations linear energy transfer (LET) strongly and characteristically modifies the quantitative relations between dose and effect *See* RADIATION BIOLOGY

When a moving charged particle (for example an electron or proton) traverses matter it progressively loses kinetic energy which is gained in diverse amounts by individual molecules along its path The amount of energy thus transferred per unit length of path is the LET It is roughly proportional at least in gases to ionization per unit path (specific ionization ion density) LET increases as the particle s velocity decreases accordingly it varies greatly along any individual path and is maximal near the end Also LET increases as the square of the charge on the particle for example the LET of an α particle is four times that of an electron or proton of the same instantaneous velocity

For experimental purposes different values of LET can be obtained in two general ways In the track segment method a beam is used made up of particles (protons) that have uniform initial velocity and produce substantially straight tracks The experiment is so arranged that they all traverse a sample of biological objects with the same linear segment of their paths Different LET values are obtained by using suitably different path segments In the track average method either entire paths are spent within the biological object or random linear segments of different paths traverse it Different average values of LET are obtained by using radiations that produce suitably different spectra of LET Although the average usually used is the arithmetic mean other averages will probably be found to be more meaningful as greater understanding of radiobiological mechanisms is achieved

In some radiobiological actions the shape of the dose effect curve is changed as LET is varied However these cases are rare in comparison with those in which only the slope is changed In the latter case the effect of LET can be expressed by a single parameter (radiobiological effectiveness RBE) which varies as the slope (or as the reciprocal of the dose in rads required to produce a given degree of effect)

For some radiobiological actions RBE decreases with increase in LET this is exemplified by inactivation of macromolecules viruses and certain bacteria For other actions RBE increases with LET in some of these cases RBE has been shown to pass through a maximum there are theoretical reasons to believe that maxima would be observed for all of them if larger values of LET were experimentally available *See* RADIATION MICROBIOLOGY

The distribution of individual energy transfers along a path corresponds to the distribution of ionized and excited molecules production of which is believed to initiate the radiobiological mechanism Because of diffusion this distribution in space lasts only 1 μsec or less Thus the observed variation of RBE with LET demonstrates that some essential part of the radiobiological mechanism is completed in a very short time

Among other interesting facts are the following (1) In at least some radiobiological actions the influence of LET is modified by other factors such as concentration of molecular oxygen (2) Influence of LET is also encountered in radiation chemistry For instance the decomposition of liquid water depends strongly on LET and this dependence is modified by oxygen Facts such as these make LET of prime interest in attempts to understand radiobiological mechanisms *See* RADIATION RADIATION BIOCHEMISTRY RADIATION INJURY (BIOLOGY) [R.E.Z.]

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Linear programming

A branch of mathematics centered about the finding of the point on a convex polyhedron where a linear function achieves a maximum or minimum Although such questions have existed in mathematics for over a century a systematic approach has existed only since World War II

The principal interest in linear programming is that many business problems can be conveniently described by it (*see* OPERATIONS RESEARCH) Linear programming is also applicable to problems in physical science economics and other parts of mathematics

General theory A typical linear programming problem is to

$$\text{maximize } c_1x_1 + \quad + c\ x$$

where x_1 x satisfy the conditions

$$x_j \geqq 0$$
$$a_{11}x_1 + \quad + a_1\ x \leqq b_1$$
$$a_{m1}x_1 + \quad + a_m\ x \leqq b_m$$

The a_{ij} c_j and b_i are constants x_1 x are variables

Sometimes the problem may be to minimize rather than to maximize sometimes some of the variables may not be required to be nonnegative sometimes some of the inequalities $a\ x_1 + \quad + a\ x \leqq b_i$ may be reversed or be equalities

The linear inequalities which the variables satisfy correspond algebraically to the fact that the variable point $x = (x \quad x)$ lies in a convex polyhedron Hence the principal mathematical bases for linear programming are the theory of linear equalities a part of algebra and the theory of convex polyhedra a part of geometry The most important theoretical foundations are as follows

If the function $c_1x_1 + \quad + c\ x$ does not get arbitrarily large for points $x = (x_1 \quad x)$ on the convex polyhedron then a maximum is attained at a vertex of the polyhedron

If there is a maximum in the stated problem then there is a minimum in the dual problem of minimizing $b_1y_1 + \cdots + b_my_m$ where $y_i \geqq 0$

$$a_{11}y_1 + \cdots + a_{m1}y_m \geqq c_1$$

$$a_{1n}y_1 + \cdots + a_{mn}y_m \geqq c_n$$

Further the maximum and minimum are the same number. This duality theorem is essentially equivalent to the minimax theorem (*see* GAME THEORY). Both the duality theorem and the min-max theorem are algebraic paraphrases of the geometric fact that if a point is not contained in a convex polyhedron then a hyperplane can be found which separates the point from the polyhedron. The duality theorem is also closely related to the concept of Lagrange multipliers (*see* CALCULUS OF VARIATIONS).

Methods of calculation. The most popular method for solving linear programs, that is, the finding of the $x = (x_1, \ldots, x_n)$ which maximizes $c_1x_1 + \cdots + c_nx_n$, is the simplex method developed by George B. Dantzig in 1947. The method is geometrically a process of moving from vertex to neighboring vertex of the convex polyhedron, each move taking higher values of $c_1x_1 + \cdots + c_nx_n$ until the vertex yielding the greatest value is reached. Algebraically the calculations are similar to elimination processes for solving systems of algebraic equations. These calculations are generally performed on an electronic computer unless the number of variables and constraints is small.

There have also been developed special methods of calculation to handle particular classes of linear programming problems such as the transportation problem discussed below.

Applications. Let a_{ij} denote the number of units of nutrient j present in one unit of food i. Let c_j be the minimum amount of nutrient j needed for satisfactory health, b_i the unit price of food i. Let the variables y_i denote respectively the number of units of food i to be bought. The the dual problem is the so-called diet problem to maintain adequate nutrition at least cost. It has been used in planning feed mixes for various types of livestock and poultry. With different interpretation of the symbols the same form describes the problem of combining raw materials in a chemical process to produce required end products as cheaply as possible.

In another interpretation let a_i be the amount of the product in warehouse i and b_j the amount required by customer j, c_{ij} the cost of shipping a unit from warehouse i to customer j. The transportation problem is to ship the required amounts to the customers at least cost. Thus, if x_{ij} is the amount to be shipped from i to j then minimize

$$c_{11}x_{11} + \cdots + c_{mn}x_{mn}$$

where $x_{i1} + \cdots + x_{in} \leqq a_i \quad i = 1, \ldots, m$
and $x_{1j} + \cdots + x_{mj} = b_j \quad j = 1, \ldots, n$

The foregoing are representative of the business applications of linear programming. Several hundred of which have now been reported. The best known applications outside business have been to economic theory and to combinatorial analysis. In both instances the duality theorem has been used to illuminate and generalize previous results.

In quadratic programming the object is the minimization (maximization) of a positive semidefinite (negative semidefinite) quadratic form over a convex polyhedron (*see* MATRIX THEORY). Efficient calculation procedures building on the simplex method are known for the quadratic case. In nonlinear programming the function to be minimized or maximized is even more general; the restraints may also be nonlinear and efficient procedures are known only for special cases. [A. J. H.]

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Linear systems of equations

Systems of mathematical equations of the form

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n &= b_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n &= b_2 \\ \cdots \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n &= b_m \end{aligned} \qquad (1)$$

where the a_{ij} ($i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$) and the b_i ($i = 1, 2, \ldots, m$) are constant or fixed numbers and the x_i ($i = 1, 2, \ldots, n$) are called unknowns. System (1) is referred to as m linear equations in n unknowns. A solution of system (1) is a set of numbers $c_1, c_2, \ldots, c_n$ such that when x_1 is replaced by c_1, x_2 by c_2, ..., x_n by c_n, every equation of system (1) becomes a true equality. The problem posed by such a system of equations is to find criteria for the existence of a solution and, when solutions exist, to obtain systematic methods for finding the solution.

An example of such a linear system of equations is

$$\begin{aligned} 2x_1 - x_2 - x_4 + 2x_5 &= 2 \\ x_1 + 3x_2 + 4x_3 - 3x_4 - x_5 &= 4 \\ 3x_1 + 2x_2 + 4x_3 + 2x_4 + 3x_5 &= 2 \end{aligned} \qquad (2)$$

This system (2) has infinitely many solutions which can be given in the form $x_1 = -c_3 - \frac{4}{7}c_4 + \frac{6}{7}$, $x_2 = \frac{1}{7}c_3 - \frac{4}{7}c_4 + \frac{6}{7}$, $x_3 = c_3$, $x_4 = -\frac{1}{2}c_3 - \frac{2}{7}$, $x_5 = c_4$, where c_3 and c_4 are arbitrarily chosen numbers.

Two linear systems of equations are equivalent if every solution of one of the systems is a solution of the other and vice versa. The system (1) is replaced by an equivalent system for which the solution, if they exist, are easily found by performing certain elementary operations on the equations. These operations are interchanging two equations, adding to one equation another equation multiplied by a constant, or multiplying an equation by a nonzero constant. By a sequence of such operations, system (1) can be replaced by an equivalent system of the following form

$$\begin{aligned} x_{1} + d_{1\,r+1}x_{r+1} + d_{1\,r+2}x_{r+2} + \cdots + d_{1n}x_n &= e_1 \\ x_{2} + d_{2\,r+1}x_{r+1} + \cdots + d_{2n}x_n &= e_2 \\ \cdots \\ x_r + d_{r\,r+1}x_{r+1} + \cdots + d_{rn}x_n &= e_r \\ 0 &= e_{r+1} \\ \cdots \\ 0 &= e_m \end{aligned} \qquad (3)$$

If $e_{r+1} = e_{r+2} = \cdots = e_m = 0$ then the solutions of the system can be obtained by choosing arbitrary values for the unknowns other than

$$x_1, x_2, \ldots, x_r$$

and solving the equations in turn beginning with the last equation for

$$x_r, x_{r-1}, \ldots, x_2, x_1$$

When the system has solutions it is said to be consistent. If any one of $e_{r+1}, e_{r+2}, \ldots, e_m$ is not zero then the equations do not have a solution and are inconsistent. In the example (2) the system is equivalent to the system

$$\begin{aligned} x_1 + 3x_2 + 4x_3 - 3x_4 - x_5 &= 4 \\ x_2 + {}^{8}\!/_{7}x_3 - {}^{5}\!/_{7}x_4 - {}^{4}\!/_{7}x_5 &= {}^{6}\!/_{7} \\ x_4 + {}^{1}\!/_{5}x_5 &= -{}^{2}\!/_{5} \end{aligned}$$

Arbitrary values c_5 and c_3 can be chosen for x_5 and x_3 respectively and the equations can be solved successively for x_4, x_2, and x_1.

The operations used in reducing system (1) to system (3) can be most effectively performed on the rows of the matrix of the system

$$A^* = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} & b_1 \\ a_{21} & a_{22} & \cdots & a_{2n} & b_2 \\ \cdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} & b_m \end{pmatrix} \qquad (4)$$

and they are precisely the elementary row transformations of a matrix (see MATRIX THEORY). The matrix (4) is called augmented matrix of the system, and the matrix

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix} \qquad (5)$$

is called the matrix of the coefficients. The rank of a rectangular matrix is defined and the method for determining the rank is given in the article on matrix theory. A necessary and sufficient condition for the existence of a solution of system (1) is that the rank of the augmented matrix A^* be the same as the rank of the matrix of coefficients A. In the example (2) the rank of the augmented matrix

$$A^* = \begin{pmatrix} 2 & -1 & 0 & -1 & 2 & 2 \\ 1 & 3 & 4 & -3 & -1 & 4 \\ 3 & 2 & 4 & 2 & 3 & 2 \end{pmatrix}$$

as well as the rank of

$$A = \begin{pmatrix} 2 & -1 & 0 & -1 & 2 \\ 1 & 3 & 4 & -3 & -1 \\ 3 & 2 & 4 & 2 & 3 \end{pmatrix}$$

is equal to 3. Therefore the system is consistent and has the solutions given earlier.

If $m = n$ in system (1) and if the determinant $|A|$ (see DETERMINANT) of the matrix of the coefficients A is not zero, then the system (1) has a unique solution which can be obtained by Cramer's rule, which gives the values of the unknowns $x_1, x_2, \ldots, x_n$ as the ratio of two determinants. Specifically, Cramer's rule gives

$$x_1 = \begin{vmatrix} b_1 & a_{12} & \cdots & a_{1n} \\ b_2 & a_{22} & \cdots & a_{2n} \\ \cdots \\ b_n & a_{n2} & \cdots & a_{nn} \end{vmatrix} \Bigg/ |A|$$

$$x_2 = \begin{vmatrix} a_{11} & b_1 & a_{13} & \cdots & a_{1n} \\ a_{21} & b_2 & a_{23} & \cdots & a_{2n} \\ \cdots \\ a_{n1} & b_n & a_{n3} & \cdots & a_{nn} \end{vmatrix} \Bigg/ |A|$$

$$\cdots$$

$$x_n = \begin{vmatrix} a_{11} & \cdots & a_{1\,n-1} & b_1 \\ a_{21} & \cdots & a_{2\,n-1} & b_2 \\ \cdots \\ a_{n1} & \cdots & a_{n\,n-1} & b_n \end{vmatrix} \Bigg/ |A|$$

In every case the determinant in the denominator is $|A|$, and for the value of the unknown x_i the determinant in the numerator is the determinant of the matrix obtained from A by replacing the ith column of A by $b_1, b_2, \ldots, b_n$. If $|A| = 0$ in this case of n equations in n unknowns the system may either be inconsistent or it may have infinitely many solutions. In the example

$$\begin{aligned} x_1 - 4x_2 + 5x_3 &= 6 \\ 2x_1 - 11x_2 + 10x_3 &= -1 \\ 4x_1 - x_2 + 5x_3 &= 0 \end{aligned}$$

$$|A| = \begin{vmatrix} 1 & -4 & 5 \\ 2 & -11 & 10 \\ 4 & -1 & 5 \end{vmatrix} = 45$$

and the unique solution is given by

$$x_1 = \begin{vmatrix} 6 & -4 & 5 \\ -1 & -11 & 10 \\ 0 & -1 & 5 \end{vmatrix} \Bigg/ 45 = -{}^{285}\!/_{45} = -{}^{19}\!/_{3}$$

$$x_2 = \begin{vmatrix} 1 & 6 & 5 \\ 2 & -1 & 10 \\ 4 & 0 & 5 \end{vmatrix} \Bigg/ 45 = {}^{195}\!/_{45} = {}^{13}\!/_{3}$$

$$x_3 = \begin{vmatrix} 1 & -4 & 6 \\ 2 & -11 & -1 \\ 4 & -1 & 0 \end{vmatrix} \Bigg/ 45 = {}^{267}\!/_{45} = {}^{89}\!/_{15}$$

If in system (1) $b_1 = b_2 = \cdots = b_m = 0$, the system

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n &= 0 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n &= 0 \\ \cdots \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n &= 0 \end{aligned} \qquad (6)$$

s called h m g neou ■ c the augmented matri f (6) differs fr m the matrix f the c efficient l y n dditi l column of zer the c matrices al ays ha e the ame r k so that a h m geneous sy em c l ys con i te t It h s the ob ious sol tion 0 $_2 = 0$ $x = 0$ which is called th t al sol t Any sol t with at least $e x_i \neq 0$ s called no tr al A hom ge eo u system of m equ t n in n kn wns ha n trivial sol tio if and ly if the ra k of th m trix f coeffi ts A i less tha n In particular f m l than n the ra k of A is at mo t m and the stem has a ont al solution Furth if $m = n$ the tem has ont i ial soluti if and only if th det rm t $|A| = 0$ In the y tem

$$\begin{aligned} 3 \ +4 \ - \ _4x_3 &= 0 \\ -2x + 3 \ _2 - \ 4x_3 &= 0 \\ 5 \ + \ _2 + \ 2x_3 &= 0 \\ -9 \ + 5 \ _2 - 10x_3 &= 0 \end{aligned}$$

th rank of $$A = \begin{pmatrix} 3 & 4 & - \\ -2 & 3 & -4 \\ 5 & 1 & 2 \\ -9 & 5 & -10 \end{pmatrix} \qquad (7)$$

is 2, so th t the y t m (7) h s no tri l l tio Th r k f A is een t be 2 by perf rmi g elementary m tr f rmat A to ed it to th form

$$\begin{pmatrix} 1 & 4/3 & - \ 5 \\ 0 & 1 & -16/17 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

System (6) i equ le t t the sy t m

$$\begin{aligned} {}_1 + 4/3 \ - \ 5/3 \ _3 &= 0 \\ x_2 - 16/17 x &= 0 \end{aligned}$$

The soluti ns are g e by $x = -10/17$ $x =$ 16 7 wher c_3 a rb t r ly ho e number

In the e ent that a l sy t m (1) h s nfi nitely many sol ti they c n be gi e a w d m the exampl (2) o lternati ly a finit numb f sol tio li l ted term f h h all sol ti n b en e tly bta d A fix d soluti f (1) i alled p rt l l tion. In th e mple (2) $x = 9/-$ $x = 9/1$ 0 $x = -7/3$ $x = 0$ p rticul sol ti If the sy tem (1) o s st t, ev ry lut on i f th f rm + c x +) whe e c s a fixed particular sol ti n f (1) d is any sol ti f the c rre pond g h m ge- eo system (6) By irtu of th s es It it i suffi t to in est g te th sol t s f th ho- mogeneo y tem (6)

Let C = ( ) c) d $C^{(}$ = c) be s l t n f the ho- mogeneo y t m (6) wr tten a n t ples Then C + C (+) ( ) + c ( ) c +) th m f the l t d eC ( ) whe e i

a fixed number i a scalar multiple f th e soluti n $C^{( )}$ It is evident that any li ear combination $e\, C^{( )} + e\, C^{( )} +$ $+ e\, C^{( )}$ of sol t n $C^{( )}$ $C^{( )}$ $C^{( )}$ of (6) i again a sol t on f (6) A set of l tio $C^{( )}$ $C^{( )}$ $C^{( )}$ f the ho- m g neous y tem (6) i called l nearly inde- pende t et if $e\, C^{(} + {}_2C^{( )} +$ $+ e\, C^{)} =$ (0 0 0) implies that $_1 = e_2 =$ $= e = 0$ Othe wi e the olut ns f rm a l early de pende t et th t is, th re exi t numbers e_1 e e n t ll ze uch that $_1C^{( )} + e\, C^{( )} +$ $+ e\, C^{( )} = (0 \ 0$ 0) A et f solution i a maximal lin arly independ t s t if the ■ t line- arly independ t an l if a et l med l y adding any ther sol t n of (6) i l early dep nd nt If the r nk of the matrix A of (6) i then the num ber of sol t ■ in a m xim l ind pe dent et i $n - r$ E ery soluti n of (6) a l ear mbina ti n $e\, C$ $+ e\, C^{)} +$ $+ e$ $C^{( )}$ of the so- luti n in a ma mal i depende t t In the ex ample (2) the c r p ding h m geneou y t m is

$$\begin{aligned} 2x_1 - \ x_2 \qquad - \ x + 2x_5 &= 0 \\ x_1 + 3 \ _2 + 4 \ - 3x \ - \ x_5 &= 0 \qquad (8) \\ 3x_1 + 2x_2 + 4 \ _3 + 2x + 3x &= 0 \end{aligned}$$

Th ra k f the m tr x A f (8) i 3 Thu th e are $5 - 3 = 2$ sol t ■ n ma mal li early i depend nt t. They n be g en s $C^{( )} = (-4$ -8 7 0 0) a d $C^{)} = (-3, 1$ 0 -1 3) E ry ol t on f (8) i g en by $e\, C^{(} + C^{)} =$ $(-4e\ -3\ _2\ -8e + e\ \ 7\ _1\ -e\ \ 3\ )$ f arbi trary e nd E ery solut on f the r g n l sy tem i gi en by $(9/7 - 4$ -3 $9/1 - 8e +$ $7e$ $-3 - e$ 3) I the e mple (7) the rank f the mat x i 2 nd the e i $3 - 2 = 1$ sol ti n in a maximal li early indepe de t s t It ca b ■ a C $= (-10\ 16\ 17)$ a d e ry sol ti n f (7) s a mult ple of C

If the y t m f quat n (1) has a sol t n then t h s r t o l solut n Th s m n that the is a soluti wh ch s bt n d by employi g nly th rat al perat of add t o ubt ac t o multipl c t n and d is n n th c effici nt f the ystem Th p rt ula l t n a well s th li early d pe de t solut n of th c rre- p d g h m g eo yst m ■ lw y b se- lected at n lly Th s e dent si ce the per t s pe f rmed n the ystem t obta n a sol t ar r t l pe at ns S EQUATIONS THEORY OF POLYNOMI L SYSTEMS OF EQUATIONS

[R A B]

Linearity

Th relat n h p th t e i t betw en two q ant t wh ha g ne f them pr d c s a d r tly p po t al h g th oth Thu mpli fie ha good l ity wh n d bl g of its nput g l t e gth always d ubl the tp t sig al str gth An l tr n t b h ■ d l n ar ty wh do bli g f th t ta s t l g d lt g rs t d uble the i st t s l f pl t c rrent

$$\begin{aligned} x_{1} + d_{1\,r+1}x_{r+1} + d_{1\,r+2}x_{r+2} + \quad & \\ + d_{1}\ x &= e_1 \\ x \ + d_{2\,r+1}x_{r+1} + \quad + d_{2}\ x &= e \\ x \ + d \quad {}_{+1}x_{r+1} + \quad + d\ {}_n x &= e \\ 0 &= e_{r+1} \\ 0 &= e_m \end{aligned} \qquad (3)$$

If $e_{r+1} = e \quad = \quad = e_m = 0$ then the olutions of the system can be obtained by choosing arbitrary values for the unknowns other than

$$x \qquad x \qquad\qquad x$$

and solving the equations in turn beginning with the last equation for

$$x \qquad x_{-1} \qquad\qquad x_{n_2} \quad x$$

When the system has solutions it is said to be consistent If any one of e_{r+1} e e_m is not zero then the equations do not have a solution and are inconsistent In the example (2) the system is equivalent to the system

$$\begin{aligned} x_1 + 3x_2 + \ 4x_3 - \ 3x_4 - \ \ x_5 &= 4 \\ x_2 + {}^{8}\!/\!_{5}x_3 - {}^{5}\!/\!_{5}x_4 - {}^{4}\!/\!_{5}x_5 &= {}^{6}\!/\!_{5} \\ x_4 + {}^{1}\!/\!_{5}x_5 &= -{}^{3}\!/\!_{5} \end{aligned}$$

Arbitrary values c_5 and c_3 can be chosen for x_5 and x respectively and the equations can be solved successively for x x_2 and x_1

The operations used in reducing system (1) to system (3) can be most effectively performed on the rows of the matrix of the system

$$A = \begin{pmatrix} a_{11} & a_{12} & & a_1 & b_1 \\ a_{21} & a_2 & & a_2 & b_2 \\ \\ a_{m1} & a_m & & a_m & b_m \end{pmatrix} \qquad (4)$$

and they are precisely the elementary row transformations of a matrix (*see* MATRIX THEORY) The matrix (4) is called augmented matrix of the system and the matrix

$$A = \begin{pmatrix} a_{11} & a_{12} & & a_1 \\ a_{21} & a_{22} & & a_2 \\ \\ a_{m1} & a_m & & a_m \end{pmatrix} \qquad (5)$$

is called the matrix of the coefficients The rank of a rectangular matrix is defined and the method for determining the rank is given in the article on matrix theory A necessary and sufficient condition for the existence of a olution of system (1) is that the rank of the augmented matrix A be the same as the rank of the matrix of coefficients A In the example (2) the rank of the augmented matrix

$$A = \begin{pmatrix} 2 & -1 & 0 & -1 & 2 & 2 \\ 1 & 3 & 4 & -3 & -1 & 4 \\ 3 & 2 & 4 & 2 & 3 & 2 \end{pmatrix}$$

as well as the rank of

$$A = \begin{pmatrix} 2 & -1 & 0 & -1 & 2 \\ 1 & 3 & 4 & -3 & -1 \\ 3 & 2 & 4 & 2 & 3 \end{pmatrix}$$

is equal to 3 Therefore the system is con i tent, and has the solutions given earlier

If $m = n$ in system (1) and if the determinant $|A|$ (*see* DETERMINANT) of the matrix of the coefficients A is not zero then the sy tem (1) has a unique solution which can be obtained by Cramer s rule which gives the values of the unknown x_1 x_2 x as the ratio of two determinants Specifically Cramer s rule gives

$$x_1 = \begin{vmatrix} b_1 & a_{12} & & a_1 \\ b_2 & a_{22} & & a_2 \\ \\ b & a_{\ 2} & & a \end{vmatrix} \Bigg/ |A|$$

$$x_2 = \begin{vmatrix} a_{11} & b_1 & a_{13} & & a_1 \\ a_{21} & b_2 & a_{23} & & a_2 \\ \\ a_{\ 1} & b & a_{\ 3} & & a \end{vmatrix} \Bigg/ |A|$$

$$x = \begin{vmatrix} a_{11} & & a_{1\,-1} & b_1 \\ a_{21} & & a_{2\,-1} & b_2 \\ \\ a_{\ 1} & & a_{\ -1} & b \end{vmatrix} \Bigg/ |A|$$

In every ca e the determinant in the denominato is $|A|$ and for the value of the unknown x th determinant in the numerator is the determinant o the matrix obtained from A by replacing the ith column of A by b_1 b_2 b If $|A| = 0$ in thi case of n equations in n unknowns the system may eith r be incon i tent or it may have infinitely many solutions In the example

$$\begin{aligned} x_1 - \ 4x_2 + \ 5x_3 &= \ 6 \\ 2x_1 - 11x_2 + 10x_3 &= -1 \\ 4x_1 - \ \ x_2 + \ 5x_3 &= \ 0 \end{aligned}$$

$$|A| = \begin{vmatrix} 1 & -4 & 5 \\ 2 & -11 & 10 \\ 4 & -1 & 5 \end{vmatrix} = 45$$

and the unique solution is given by

$$x_1 = \begin{vmatrix} 6 & -4 & 5 \\ -1 & -11 & 10 \\ 0 & -1 & 5 \end{vmatrix} \Bigg/ 45 = -{}^{285}\!/\!_{45} = -{}^{19}\!/\!_{3}$$

$$x_2 = \begin{vmatrix} 1 & 6 & 5 \\ 2 & -1 & 10 \\ 4 & 0 & 5 \end{vmatrix} \Bigg/ 45 = \ {}^{195}\!/\!_{45} = \ {}^{13}\!/\!_{3}$$

$$x_3 = \begin{vmatrix} 1 & -4 & 6 \\ 2 & -11 & -1 \\ 4 & -1 & 0 \end{vmatrix} \Bigg/ 45 = \ {}^{267}\!/\!_{45} = \ {}^{89}\!/\!_{15}$$

If in system (1) $b_1 = b_2 = \quad = b_m = 0$ the system

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \quad & + a_{1n}x = 0 \\ a_{21}x_1 + a_{22}x_2 + \quad & + a_{2n}x = 0 \\ \\ a_{m1}x_1 + a_{m2}x_2 + \quad & + a_{mn}x = 0 \end{aligned} \qquad (6)$$

called h m ge eou S nce the augme ted matrix f (6) d ff rs from th matrix f the c efficients by an add u al c l mn of ze the e matrices al ys h e the ame r k so that a hom geneou system lway co i tent It has the b s l u n $0\ x = 0$ $x = 0$ which i all d the tr l sol t A y l t n with t l t r $\neq 0$ is c lled no t i ial A h m ge eo system of m equat in n unknown ha a n m al sol ti n if a d ly if the rank of th mat i f coeff ts A is less than n In particular if m l th n th ra k of A is at m t m and the tem has a tri ial sol t n Furthe if $m =$ the syst m h a no t i ial sol t on if a d ly if th det rmmant $|A| = 0$ In th s y tem

$$\begin{aligned} 3\ _1+4 \quad - \quad 2x &= 0 \\ -_2x_1+3 \quad - \quad 4 &= 0 \\ 5\ _1+ \quad _2+ \ _4x_3 &= 0 \\ -9\ _1+5\ _2-10x_3 &= 0 \end{aligned}$$

the rank f
$$A = \begin{pmatrix} 3 & 4 & -? \\ -2 & 3 & -4 \\ 5 & 1 & 2 \\ -9 & 5 & -10 \end{pmatrix} \tag{7}$$

is 2, so th t th sy t m (7) ha a no tri l lu tn The k f A i seen t b 2 by pe f rming elementary w tr n f rmat n A to edu it to th f rm

$$\begin{pmatrix} 1 & \frac{4}{?} & -\frac{?}{?} \\ 0 & 1 & -\frac{?}{17} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

System (6) eq i le t t th ystem

$$\begin{aligned} + \tfrac{4}{3} \quad - \quad \tfrac{?}{?} &= 0 \\ _2 - \tfrac{1?}{17}x_3 &= 0 \end{aligned}$$

The sol tio a g n by $x = -10/17$ $x_2 = 16\,?$ $= _3$ h s a bit a ly h number

In the ev nt th t l e r sy tem (1) h i fi nit ly many sol t on they c b g e as w do in the ampl (2) n It rn t ly a fi ite numbe of sol t on c k l ted n t rm f h h all sol ti n n be tly bt ed b n fixed l t f (1) c ll d p rt ula solut n. In th ex mple (2) $x = \frac{?}{7}$ $x = \frac{?}{?}$ $0\ x$ $-\frac{?}{?}$ $= 0$ s pa ti ul r sol t o If th sy t m (1) i c te t, every s lut o s f th f rm $c +$ $x = c_2 + c$ $+ c$ wh re c s fi ed p rti l r sol tion of (1) and $c^{( )}$ $c^{( )}$ c, is any sol t on f the rrespo ding homoge neo sy t m (6) By i tu f th e lt m offi t t e t g t th sol ti n f th ho m geneou y t m (6)

Let $C = (c^{( )}$ $( )$ $c^{( )})$ nd $C^{( )} =$) be sol t o f the h mogeneo sy t m (6) writte n t ples The $C + C$ $= (\ ( ) + c^{( )}$ $( ) + \ ( )$ $eC +$) i th m of th l t d c) whe e

a fixed number i a scalar m ltiple f the solution $C^{( )}$ It i evident that a y l e r combinatio $e\,C^{( )} + {}_2C^{( )} + \quad + \ C^{( )}$ of olutions $C^{( )}$ $C^{( )}$ $C^{( )}$ of (6) is gain a solution of (6) A et of solut n $C^{( )}$ $C^{( )}$ $C^{( )}$ f the ho m ge eous y tem (6) i called a l nearly inde pende t et if ${}_1C^{(1)} + e\,C^{(2)} + \quad + e\,C^{( )} =$ (0 0) impl e that $e = e = \quad =$ $e = 0$ Otherwi the lutions f rm a line ly de pendent et that i there exist n mber e_1 r not all ero uch that $e\,C^{( )} + e\,C^{( )} + \quad + e\,C^{( )} = (0\ 0)$ A t f sol t i a m x mal li rly ind pendent s t if the et i li e arly indepe dent and if a t f rmed l y add g a y ther sol t n of (6) i lin rly d p dent If the r k of th matrix A f (6) i th n the n im ber of luti n a ma mal independ t et i $n -$ F ry sol t n of (6) is a l ear c mbina ti n $C^{( )} + e\,C^{( )} + \quad + \ C^{( )}$ of the so l t ns n a m mal i dependent set In the ex ample ( ) the rresp d ng h m geneou sy tem is

$$\begin{aligned} 2x_1 - \ x_2 \qquad - \ x_4 + 2x_5 &= 0 \\ x_1 + 3x_2 + \ 1x \ - 3x \ - \ x &= 0 \\ 3x \ + 2x_2 + \ 1x \ + 2x \ + 3x_5 &= 0 \end{aligned} \tag{8}$$

The rank of th matri A f (8) i 3 Thus there re $5 - 3 = 2$ sol t n a maximal lin ly i d p nde t et They can be gi en s $C^{( )} = (-4\ -8\ 7\ 0\ 0)$ nd $C^{( )} = (-3\ 1\ 0\ -1\ 3)$ E ery sol t n f (8) i g e by $C^{( )} + \ C^{( )} = (-4 \quad -3 \quad -8 \ +e \ 7 \quad -e \ 3\ )$ f r rbi trary e a d e E ery sol ti f the rig l ys tem is g e by $(\frac{?}{7} - 4e - 3e \ \frac{?}{?}{}_1 - 8e_1 + {}_2\ 7e \ -{}_3 - e \ 3\ )$ In th e ample (7) the nk of the m tri 2 d there i $3 - 2 = 1$ solut n i a m xim l l e rly nd pend t set It can be g en as $C^{( )} = (-10\ 16\ 17)$ nd every solut n of (7) i a m ltipl f $C^{( )}$

If the y tem f qu t s (1) h s a sol t the t h a r t l sol tio Th s me ns that the e is sol t n wh ch obtai ed by mpl y g nly th at l per t n f dd t o bt ac ti n m lt pl ti a d di o th co ffi e t of the y t m The p tic l r ol tio a well as th li rly nd pe dent sol t o f th c re spo d g h moge eo sy tem c n lw y be e l ted ti lly Th i e de t s c the pe a t s perf rmed n the y t m t btai n sol t o a r t o l op at ns S EQUATIONS THEORY OF POLYNOMIAL SYSTEMS OF EQUATIONS

[R A B]

Linearity

Th r lat n h p th t i t b tw two q tit e whe ch g in e f th m p od s a d ectly p p t l ch g i th ther Th ampl fi g d l a ty wh n d i bl g of it np t gnal st gth lway d bl th tput gn l t gth A el ct t b h g d l nea ty when d g f the i t t t l g d lt g rv t d bl th i ta t e l e f pl te e t

In television uniform linearity of scanning is essential for uniform spacing of picture elements in each horizontal line and uniform vertical spacings between scanning lines Poor linearity causes the picture to be compressed or stretched in some area so that circles of te t patterns become egg shaped or even more greatly distorted [J MR]

Linen

A widely used cloth made from flax fibers Linen is noted for its evenness of thread fineness and density Its uses include garments tablecloths sheeting towel and thread

The flax plant which supplies the fiber needs a short cool growing season with plenty of rainfall (see FLAX) The U S S R leads the world in growing flax for fiber The manufacture of the fiber into fabric requires unusual care throughout each proc ■ s in order to retain the strength and beauty of the fiber

Processing the fiber Seeds and leaves are removed from the stems of the flax plant by passing the stalks through coarse combs a process called rippling Bundles of stems weighted down with heavy stones to ensure complete immersion are then steeped in water The wetting allows the tissue or woody bark surrounding the hairlike flax fibers to decompose thus loosening the gum that binds the fibers together This decomposing or fermentation is called retting

After removal from water the stems may be spread out on the ground for a week or more After the woody tissue has become dry it is cru hed by fluted iron rollers After this breaking operation there remain only small pieces of bark called shives The shives are removed by means of rotating wooden paddles thus finally releasing the flax fibers This operation can be done either by hand or with machinery The simple combing process known as hackling straightens the flax fibers ep arates the short from the long staple and leaves the longer fibers in parallel formation For very fine linen hackling is usually done by hand and ■ repeated a finer comb being used with each hackling treatment Coarse linen is hackled by machine

Properties of flax fiber Under a micro cope the flax fiber shows hairlike cylindrical filaments with fine pointed ends The filaments are cemented together ■ intervals in the form of markings or nodes by a gummy substance called pectin (see PECTIN) The long flax filaments contain a lumen or central canal The fiber resembles a straight smooth bamboo stick with its joints producing a slight natural unevenness that cannot be eliminated Chemically the flax fiber is compo ed of about 70% cellulose 25% pectin and the remainder of woody tissue and ash (see CELLULOSE) From such fibers linen yarns are produced that have a smooth straight compact and lustrous appearance See FIBER NATURAL TEXTILE [M D P]

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Lines of force

Imaginary lines in fields of force whose tangent at any point give the direction of the field at tha point and whose number through unit area perpendicular to the field represents the inten ity of th field The concept of lines of force is perhaps mos common when dealing with electric or magnetic fields

Electric lines of force These are lines drawn to represent or map an electric field graphically ■ the space around a charged body They are of great help in visualizing an electric field and in quantitative thinking about such a field The direction of an electric line of force at any point is drawn parallel to the direction of the electric field intensity E at that point The quantitative convention is that the number of electric lines of force drawn through an imaginary unit area of surface perpendicular to the field shall be numerically equal to E at that area From this quantitative convention and using the rationalized mks system of units q/ϵ_0 lines of force originate on a positive charge q (in coulombs) and a like number terminate on a negative charge q of the same magnitude Here $\epsilon_0 = 8.85 \times 10^{-12}$ coul²/newton m² is the permittivity of empty space See ELECTRIC FIELD

Magnetic lines of force A magnetic field of strength H may also be represented by lines called lines of force The number of lines of force per unit area of a surface perpendicular to H is numerically equal to the value of H The lines of magnetic force due to currents are closed curves as are the lines of magnetic induction Magnetic lines of force due to magnets originate on north poles and terminate on south poles both inside and outside the magnet See MAGNETIC FIELD [R P WI]

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Link

An element of a mechanical linkage A link may be a straight bar a disk or it may have any other shape simple or complex It is assumed for simple analysis to be made of unyielding material—that is its shape does not change A link ■ capable of turning about an instant center The frame or fixed member of a linkage is one of the links whether the frame ■ fixed relative to the earth or fixed relative to a movable body such as the chassis of an automobile By this definition auxiliary members of mechanisms such as belts springs and other flexible connectors and liquid columns in hydraulic systems are not links [E S F]

Linkage genetic

The presence of numerous pairs of genes in the same chromosome or homologous pair of chromosomes Two or more gene differences do not egre gate independently into separate cell nuclei when they are located in homologous chromo ome They remain in their original combinations unle s a mutual exchange of equivalent chromos mal seg

nt occur bet ee p red homologs in a proce s own as cro ing er See RECOMBINATION CE TIC SEX LI KED INHERITA CE. [D D P]

inkage mechanical

set of rigid bod es, called links joined together t pivots b mea of p s q alent device bod is n idered to be rigid if f p actical rposes the distances between points on the body not change Li kages are used to tran mit power d inf rm ti n Th y may be mpl yed to make a oint the linkage follow a prescr bed curve re ardl f the inp t mot on t the li k ge They used to p od c an a gular or l near d pl ce nt f( ) here f( ) a g en f nct n of a d placement

If the links are bars the l kag termed a bar linkage. In first app o mat s a bar may be treated as a tr ght l e segme t a portion f a curve, and a p vot m y be t ted as a common point on the bars connected at the p ot A m n f rm f bar linkage i then one for wh ch the ba re estri ted t a gi en plane such as a four bar linkage (F g 1) A body pi ted t a fixed base a d t ne or m e oth l ks is a crank. A cra k 4 in Fig 1 r t tes, link 2 (lso crank) scillates b ck a d forth Th f ur b r link thus tran forms a r tary m ti nt a oscillat ry o e t vi e s Link AB marked 1 is fi ed Link 2 m y be replaced by a lide 5 (Fig 2) As e d D of crank 4 rotates pi t C describes the same curve a befo e The sl der m es in a fixed groove

A comm nly occurring a i tion f the f ur bar linkag is th link ge u ed in ec procating en

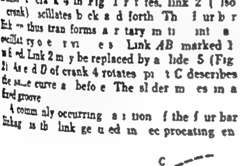

Fig 1 Fou -b l k g

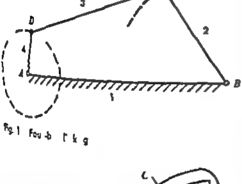

Fig 2 Eq ival t of f -b l k g

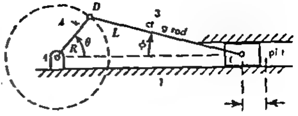

Fig 3 Sl d -cra k mech m

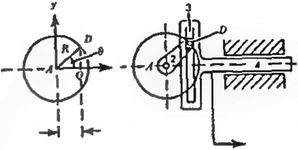

Fig 4 Scot h y ke

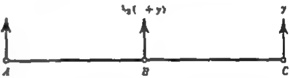

Fig 5 Add t w th a l

gines (Fig 3) Slider C is th p ston in a cyli der l k 3 i the nnecting rod a d li k 4 is the crank This mechani m t an f rms a line to cir ular motio or e The str ight sl de i ll with the rank enter is equi alent to pi ot t th end f an infin tely l g l nk Let R be the le gth of the nk, L th length of the co ecti g od wh le θ and ϕ de te the a gles of the c ank nd rod (F g 3) Let x d ot the coord nat f the pi ot C measured s that $x = 0$ whe $\theta = 0$ Le gth L normally d minates rad u R whe n the f ll wi g app oximat rel ti n h lds

$$x = R(1 - \cos\theta) + \frac{R^2}{2L} \sin^2\theta \qquad (1)$$

A Sc tch y ke i employed t c n ert ste dy r t ti nt s mple harm ni m tion (Fig 4) The a gle of the a k 2 with espect to th h r izo tal de ted by θ a d the oord nate of the sl de 4 by x If R aga n de the length f th cra th foll wi g hold

$$x = R\cos\theta \qquad (2)$$

I c mput m ha sm sl de 3 can be m ed al g the c nk th t the mpon nt of a ect c n b bt i ed mecha cally

A lever s n rmally u d stood t be a ba con nected t th e th link A lev s ften sed for dd t (F g 5) P nt B t the c nte of l e AC It med th t x d y ar ume i cally m ll mpa ed t the l gth of th l er

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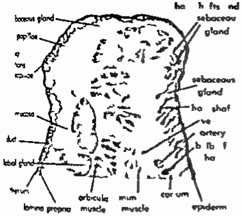
An element of a mechanical linkage A link may be a straight bar a disk or it may have any other shape simple or complex It is assumed for simple analysis to be made of unyielding material—that is its shape does not change A link is capable of turning about an instant center The frame or fixed member of a linkage is one of the links whether the frame is fixed relative to the earth or fixed relative to a movable body such as the chassis of an automobile By this definition auxiliary members of mechanisms such as belts springs and other flexible connectors and liquid columns in hydraulic systems are not links [E S F]

Linkage genetic

The presence of numerous pairs of genes in the same chromosome or homologous pair of chromosomes Two or more gene differences do not segregate independently into separate cell nuclei when they are located in homologous chromosome They remain in their original combinations unless a mutual exchange of equivalent chromosomal seg



Section through lowe l p f ma (From R. O Greep d H st logy McG w-Hill 1954)

Cheeks. S nc th m th pen g of mammal ll in f o t of the j ints f th jaw reg on created m ea h d kn wn a th heek. Ea h is contin u n b ckw rd f th l ps and is es en tially sim lar in tru t Some rodents d Old World m keys ha expa ded thes p ces t heek po hes wh h re sed f the t mpor ry st rag d carri ge f food. The pocket g pher ha e p e po ches th heek regi n, but th in ta they ar ha l ed a pe g onto th external rf ce d t ant th m th.

Morphology Struct rally a l p pl te f l untary muscl th ter sid rfa ed with kin and th m r d with a m memb At the red m gi betw these rf es there s a z n that is tran t l between these tw overi g. Th kin f th t d f th l p i qu t typ al, th thin p d rm wh h h were both p qu d e ratified Beneath th piderm l cover lie hai f ll les weat gland d seb eou glands Cent lly with n th l p a pl t f k le-tal m scl wh h f rmed mostly by th b cula m scl Slip f m l sert m g th on ec tiv ti. bundles f th k d th lat end th k m b l Hen th m scl her be l gs to th fa l muscles f exp es th mi met m les Th n er d f th l p a typ l cou memb Its t t fi d quam ep th li m m kedly th ker th th piderm but t m fied Th. typ f ft ep th l um ha art t f w t f es bject t frict d not bsorpti C p f ded l b l gl d oc d p r wh t may be lled bm cosal ! Th se tio l my m cu a d ther d t pen t th est b l Th red ma gi n termed t tru tur betw en th ter d er rf es Th ep th l um tr n l ent T ll as-cul p p ll f nect t dent the ep th l m f t w d th f T blood essel exten l t ther p p ll d th ta ned blood h w th gh th g g th l p ed l S m l l rs end gs a l ght los t th f so th t the m g l gre h ghly sen t Cl d f th zon d the soft pithelium ha t be m i t ed frequently by wip-i g with the t g e Acc r l gly the labial margin i s bject t happ ng r ra k g

Development Th low r lip a d j w de elop fr m the fu i n of tw c mponent th m nd l lar processes wh le th upper lip a d j w dev l p fr m four the tw m xillary a d tw med na l proces es Th pper l p is m e pr e t mi haps in devel pm t th e mm nest f wl h i h e lip At times thi cl ft l k d fect l es the upper jaw bo e and th m be ml ed with left pal t Lip be me parat tities wh n the ep thel m f ach primit e jaw region gr w i wa d a a plate and then clea es in two th ereby prod cing the estib le d par t g the lip fr m the g m S ORAL GLAND [L.B.A.]

Lipid

O e f a ls f compound whi h t in l ng h n al ph t hyd oc bons (cycli o acylic) a d ther de i ati es such a ac d (f tty a d) al oh l am es am o alc hol a d ald hydes Th p ese f the l ng l ph t chai the ch t i ti compo t of l pid co fe d t ct l bil ty pr pert es n the mpl r members f th l f t lly occ rr g compo d Th s led t th t dit al d fi ti n f l pid ub-t es whi h a e l ble in w ter b t soluble i f t sol ent s h a th r chl f rm, d benz e H weve those l p d (p rticul ly glycol p d d phosph l p d) wh h cont i pol r r mpo-ent in the m lecule m y be i soluble in thes sol ent a d me are even sol bl n w te (s SOLVE T) Most f th phosphat des a good em l fyi g g t S e EMULSIO

Classification Th l pid ar g erally cla i-fied t th f ll wi g gr p

A S mple l p d.

1 T gly rides f t d oil a e fatty d esters f gly l E amples la d, c rn l, tt ed d butter
2 Wa es r fatty a d ester of l ng-cha n l h l E mples i beesw x, perm c ti, nd carn b w x.
3 Ster id r l p d deri ed f om parti lly mplet ly hydr gen ted phen th e Ex mples r h lest r l d ergosterol.

B Complex l pid

1 Phosph t des r phosph l p d l p ds wh h co ta phosph ru and n many i t e tr gen. Examples lec th n, ph l n, a d phosph t dyl inos t l.
2 Gly l p d l p d which t in bo-hydr t es d Examples e t l glyco-des e b os des d pl t phytogly o-l p d
3 Sph g lip d e lip ds conta ing th lo g ch in m al h l sph gosine d its d ri t es E mples phing my l eram des d ereb os des

Th cl fic t n heme t rigid s e phi g l p d e f und whi h co t ph ph ru

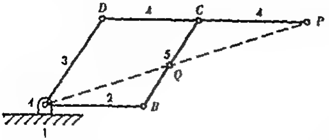


Fig 6 Pantograph

Levers with a fixed pivot (fulcrum) are particularly useful for amplifying or attenuating linear displacements and forces

The pantograph shown in Fig 6 is a five link mechanism employed in drafting to magnify or reduce diagrams As point Q on link 5 describes a curve point P on link 4 will describe a similar but enlarged curve Here $ABCD$ is a parallelogram Pivot A is fixed

A mechanism composed of six links introduced by Joseph Whitworth (1803–1887) makes the return stroke of a body in oscillatory linear motion faster than the forward stroke Universal joints for transmitting motion between intersecting axes and escapements permitting rotation about an axis in one direction only are examples of the many kinds of linkages used in machines However complicated linkages are becoming obsolete because of the ease with which information and power can be transmitted by electrical hydraulic and pneumatic means [R O]

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Linoleum

A floor covering made by applying a mixture of gelled linseed oil pigments fillers and other materials to a burlap backing and curing to produce a hard resilient sheet The surface may be further decorated by printed patterns The term is also applied although incorrectly to similar resilient floor coverings made of other resins or related materials See DRYING OIL [F SD]

Linseed oil

A product made from the seeds of the flax plant (*Linum usitatissimum*) by crushing and pressing them either with or without heat After the linseed oil is extracted it is formulated either raw or boiled in various grades and with various drying agents such as litharge minium and zinc sulfate Its most common uses are as the vehicle in oil paints and as a component of oil varnishes after a longer period of boiling and other preparation as a printing and lithographic ink base in the manufacture of oilskin raincoats oilcloth and linoleum and in some soaps Oil cake the residue of the crushed seeds is a protein rich material used for cattle feed Most linseed raised for oil comes from Argentina Russia and India with lesser quantities from the north central United States and Canada It was first used as a drying oil in the twelfth century with the introduction of oil painting See DRYING OIL FLAX SURFACE COATING [F CO]

Lion

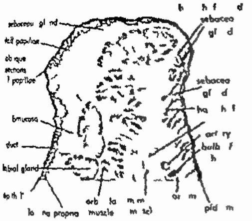
A large carnivore *Felis leo* of the family Felidae now limited to southern and central Africa At one time it was found over much of Asia and southern Europe The male lion may attain a weight of 600 lb and a length of 11 ft including the tail Females are somewhat shorter and much lighter

The African lion *Felis leo* length to 8 ft (From P M Duncan ed *Cassell's Natural History* Cassell 1883)

Because of relentless hunting lions are constantly being reduced in numbers and are losing territory They live in groups called prides and show a degree of cooperation in the securing of food and rearing of the young not practiced by other cats Most of the work of securing food for the pride is done by the female Lions are greatly harassed by a host of smaller animals that try to steal part of the kill when the lions have succeeded in the hunt See CARNIVORA [J D R]

Lip

A fleshy fold above and below the entrance to the mouth of mammals Even the lower vertebrate with movable jaws such as fishes amphibians and most reptiles have folds of skin external to the jaws and teeth These folds covered superficially with epithelium are usually soft and supported internally by connective tissue By contrast in turtles birds and the lowest mammals (monotremes) the epithelium is cornified and hard so as to form a beak or bill Nevertheless only the typical mammals (marsupial and placental mammals) possess a highly developed type of true lip These are separated by deep clefts from the jaws and are made mobile by containing muscles belonging to the facial group The separating clefts produce the constitutes the vestibule of the mouth The increased size and mobility of the lips of mammals are adapted to such functions as sucking drinking grasping food and holding it again to the teeth The opening into the mouth is expanded or restricted at will The lips of man are just as important in producing articulate speech and they aid in facial expression



Sectio thro gh th l w l p f m (Fr m R O G p ed H st logy M G w-H ll 1954)

Cheeks. S n e the m uth open ng of mammals lies w ll m fro t of the joints f the jaw a region u ere ted n each ide known a th ch ek. Ea h s a c t u tuo ba kwa d f th l p and s essen tually iml m truct re Some rodent and Old W rld m nke h e xpanded th e sp ces into cheek p uches h h e ed f r th temporary st g and carr ag of food The pock t gophe s ha e xpa e po ches i th cheek reg n but in th n t n e th y ar ha r l ned a s pening o to the e t rnal rfa e a d not nto the m uth

Morphology t tu ally l p a plate l ol unt ry m s l th te de urfa ed w th kin a d th inne d with m c u memb ne At th red m rgin b twe these u faces th ts z n th t s tran iti nal between these two c vet ngs Th ki f th te d l th l p q ite typ al th ll n pid rm s wh h however both p qu and rn fi d B n th th p derm l o r h h f ll l sw at gl d nd eba eo s gl d Ce t llv w th n th l p pl t of k le- t l muscl wh ch i f rmed mo tly bv th o b l r muscl Sl ps f m l ert m ng the nnec t -is u bu dles of the k n and th s l t read th kin m bile Hen the m le here b long t the fa l m l s f xp s on th m m i c mu l Th n r d of th l p a typi l m o m mb e Its stratified q m p the- l m i m k dl th k th th p d rm s but s n t e m fi d Tl s typ f ft pithel m s ha a t t f w t u f e bject t f ct n and a t b pt Gro p of r ded lab l gl nds u deep in h t may b alled ubmu osal l je Th er t n a l my m u d the d t ope t th t bul The red marg n n f rmed t t ct b t the t r and inner f c Th ep th l m i t a l ent Tall s l p p ll e f n t e t ue s d nt th ep thel m f t w d the u f T y blood s l ex d nto the p p'll nd th t ned bl od h w th gh th g g th l p d ol r S m la ly nerv d g br ght l e t th n fa tl t th m rg n l r g o h ghl t Cl d ab t n tl n d th fr

epithelium has to be m i tened frequentl l y wip- ing with the t gue Accord ngly tl lab al margin is subject to cl pping or cra king

Development Tl e lower lip and jaw develop f m th fu ion of two component the mand bular proce es while th upper lip and jaw devel p from four the two m axillary and two median na al proce e The upper l p i more pr ne t m hap in de el pment the commonest of wl i h i hare l p At times th cleftlik defe t in l e the uppe jaw bone and then may be c mb ined with a left p late Lip become eparate entiti when the ep tl eli m of e ch prim ti e jaw r g g ows inwar l a a pl te and then cl a e in two thereby p od c ng the vestibule and ep rat ng the lip from th gum *Se* ORAL GLAND [L.B A]

Lipid

One of cla of comp und which contain l ng ch in aliphatic hydroc rbons (cycl c o acylic) and their de ti es uch s a ids (fatty acid) lc hols am es amino alcohol and aldehydes Th presen e f the l ng liph t cl ain as the ch racteri tic c mponent of lip d o fers di tinct ol b l ty pr p t e on the s mple members of th cla of naturally occurring compo nds Thi led to the t ad ti nal defin tion of lip ds a sub tan es whi h in oluble in water but s lubl in fat l e ts su h as ethe chl roform and be zene H we er those lipid (particularly glycol p d and phosphol pids) whi h c ntain pol r c mpo- n nt in the m lecule may b ins luble in these sol nt and me are even s l ble in wat r (s e SOLVENT) M st f th ph phat des are good em l fy ng age ts *See* EMULSION

Classification Th l p ds are ge erally cla fi d into th f llowi g gr ups

A S mple l pids

1. T iglycer d s o fat and ils a e fatty d e te s f glyce ol Ex mples ar l rd corn il tton ed oil and butte
2. W e are fatty a id est r of l ng-cha n alc h ls E ampl are beeswax permaceti and c rn b w x
3. Steroids lip d de ed f om p rtally o compl tely hyd ogenated ph n nthrene Ex amples are chol te ol and e gosterol

B C mpl x l pids

1. Ph phatide r ph sph l p d a l pids wh ch o ta n ph ph ri s d in many n tan es n tr g n Example are lecith n c phal n d ph ph t dyl sitol
2. Glyc l pid are l pid wh h ontain ca bo- hydrat r idue E amples a t l glyco s d e eb d s and pla t phyt glyco- l p ds
3. Sph n ol p d ar l p ds taining the long ch n amin al oh l phin osine and it der ati e E mple re sph gomyel n c mides and br d

Th l fi at o s h me s n t rng d n e *ph ng l p d r f u d wh ch conta n pho ph r*

and carbohydrate and glycolipids which contain phosphorus Those lipids not included in the above groupings are of the chemically simpler type and include the fatty acids alcohols ethers such as batyl and chimyl alcohols and hydrocarbons such as the terpenes and carotenes

The fatty acids found in lipids may be saturated or unsaturated cyclic or acyclic and contain sub stituent such as hydroxyl or keto groups They are combined in ester or amide linkage

The alcohols likewise may be saturated or un saturated and are combined in ester or ether link ages in the case of α β unsaturated ethers these are best considered as aldehyde derivatives

The amino alcohols found in lipids are linked as amides glycosides or phosphate esters Sphingo sine is the amino alcohol found in animal tissues and phytosphingo ine is its equivalent in the plant kingdom One long chain diamine (necrosamine) has been isolated from the lipids of the bacterium *Escherichia coli*

Occurrence Lipids are present in all living cells but the proportion varies from tissue to tissue The triglycerides accumulate in certain areas such as adipose tissue in the human being and in the seeds of plants where they represent a form of energy storage The more complex lipids appear to be more nearly structural elements and occur in the membranes of cells and of special bodies within the cells More active tissues generally have a higher complex lipid content for example the brain liver kidney lung and blood contain the highest concentration of phosphatides in the mam mal Fish oils are important sources of vitamins A and D and seed g rm oils contain quantities of vi tamin E The vitamins K occur chiefly in plants and microorganisms and carotenoids are widely distributed in both the plant and animal kingdoms Waxes are found in insects and as protective agents on plant leaves and the cuticles of fruits and vegetables (for instance the bloom on grapes and plums) Soybeans are used for the commercial preparation of phosphatides

Extraction Many of the lipid particularly glycolipids phosphatides and steroid ester are present in the tissue in association with other cell components such as protein The nature of the linkages in these complexes is not fully understood although they are most certainly not covalent Combinations of lipid and protein like lipopro teins and proteolipids ha e been isolated from sources such as blood serum and egg yolk For the efficient extraction of lipids from tissues these complexes must first be disrupted and this is usu ally accomplished by dehydration procedures such as freeze drying or acetone extraction or by dena turation with alcohol before extracting the ti sue with suitable lipid solvents The u e of mixed sol vents uch as ethanol and ether ethanol and ben zene or chloroform and methanol allow disrup tion dehydration and extraction in one opera tion Partial fractionation of lipid may be effected by succes ive extractions with different sol ents

Separation The difficulties involved in the epa ration of lipids have held back progre s toward their chemical identification Prior to 1948 solve fractionations or the use of specific complexu agents such as cadmium chloride for the separ tion of lecithin were the only methods availabl Since then the use of column *chromatograph* particularly on alumina and silicic acid counte current distribution and ion exchange re ins h allowed far more rapid progress in separation an also has led to the di covery of previou ly und scribed lipids Other methods which allow electi degradation of certain lipids either chemicall (for example the use of dilute alkali to cau e pre erential hydrolysis of esters) or enzymatically ar also being used succe sfully for the separation c certain lipids *See* CHROMATOGRAPHY

Identification Most of the conventional analyt cal procedures are used in the identification lipid samples Physical methods such as infrare and ultraviolet spectroscopy optical rotation an proton magnetic resonance studies have been used Gas phase chromatography is playing an impor tant part in the identification of fatty acid Par ticularly useful are paper chromatography bot reversed phase and silicic acid impregnated qual itative and quantitative methods for the determina tion of esters aldehydes carbohydrate long chain basis and the other important components of lip ids such as glycerol glycerophosphate ethanola mine choline erine amino sugars and inositol and elementary analyses for nitrogen and phos phorus The nitrogen to phosphorus ratio of a phosphatide sample has long been u ed as a cri terion of purity because carbon and hydrogen analyses on a single phosphatide species are not highly revealing owing to the pectrum of fatty acids that may be present The degree of unsatura tion is determined by hydrogenation or iodine num ber determination and free hydroxyl groups are expressed by the acetyl value Lipid samples al o may be hydrolyzed under a variety of acid or alka line conditions and the products investigated by paper chromatography *See* CARBOXYLIC ACID FAT AND OIL, EDIBLE FAT AND OIL NONEDIBLE GLYCOLIPID LIPID METABOLISM PHOSPHATIDE SPHINGOLIPID STEROID TERPENE TRIGLYCERIDE VITAMIN WAX ANIMAL AND VEGETABLE

[H F C R H C]

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Lipid metabolism

Lipids are compounds known as fat waxe phos pholipid glycolipid and sterols The lipid are the most concentrated source of energy for li ing organi ms yielding more than twice as much en

ergy per gr m as ca bohydr te or protei They prol g th t m food remains in the t ma h and thus d l the on et f hunger Lipid al o provide th essential fatty a id uch as l n l ic l n lenic a d ar h do ic and ar the m an l y which the fat sol ble vitami (A D E a d K) enter the body Th bod l p d in stored fat are s urc s of food d n fa t g and su bcutaneou f t n u late again t lo f heat Th s art cle di us e the utilizati n and synthe of l p d s the m mmal

Fat digestion and absorption The dige ti n process n the intest e renders fat water l ble to fa lit te absorption through the wall of the in testin and lymph cha els

Fat d sti Little fat d gestion ccurs in the st ma h cept in nf ts In the ntesti es, the b the p n atu j e and a ecreti n fr m the intest m (the succ s e teric) re the ag nts h h d gest fat. The b le fo med by the l er nd collects in the gallbl dd r From t m t t m it d scha ged f om th ga llbladd r int the in te tines a d mixes w th th food Th bile c ntains pigm nts d tw bile ac ds ta roch l c and gly roch l c d The a deterg nt wh ch a t t k the ngested fat w t r l ble When the a d t nt of th st mach a d ch rged int the d ode um (th fi t po t on f th intest e) a h rm n ecr t n, s d l rged by the d d num int the blood th s t m lat th p r to se ete pan at c ju ce The pa r at c j on tai enzym wh h dig st prote n and a bohy d e d the nzym l p e wh h by hyd oly is f the ngested fat, f rm gly er l and f e fatty d Th s acti n s ls a ded by the suc u n teri The p n re t ju e th b l nd th uc c nte u m x with the food and d gest t t f rm hyl

Fat abs ptio The d gested me l r hyl mainly ab bed t th bl d thr gh th t t n l w ll but th d g ted fat e al o ab bed thr gh t m abl lymph h nnel These o lesce t f rm th tho a d ct, which d sch rge t t t nto l rg l lo d es ls the jug lar e i the hest If th pa ag f bile nto th m i hl ked by ea n f d a e th am m l d t b ch l The stool th n b com lay col d be a e of x s f the o ps of fatty a id wh h r n t ab orb d The b le id and b le p gme t e te g the bl od by ab pt n f om th hyl a e m ed by th l a d aga n d sch ged s b le t the r t t n s Th y l t nly n rves b le p gm t nd the b l a id b t p e t the r pp a m n e ess n th blood

St t h Fa l l d gest on of f t d e t b n e f b l p e t ju e s lt n n unu ual am unt of fatty material in the tool Thi c ndition is t rmed steat rrhea

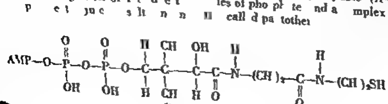
Lipids in the blood F ur f rms are rec gnized (1) t iglycerides coml inati ns of fatty acid with glycerol (2) n nesterified fatty acid (NFFA) fatty acids unc mbined with glycerol which l ave recently rece ed att nti n partic larly l ecau e of their ncrea e in diabetes (3) chol terol a com plex ter l ompo nd wh e con entrati n in the blo d ha ignifi ance in hyperten i n (4) ph phat des oml ination of fatty acid with ph s phates and lecith n Fat in the l lood exi t in th f rm f mall dr pl t c lled chyl mic a Lipemia mean an ex e of lip d in the blood er the norm l *Se* PHO PHATIDE STEROL

Turnover of body lipids Fat n the l ody depot have a very act m t bol m They are c tinu ally bei g dep ted nd u ed up Th f tty ti e can synthe ze new fat f m carbohydrate and other s ur e mate i ls In the teady state when total body fat is co stant the rate at wh ch fat i oxidi ed and resynthesized i alled the turn r rate It an b mea ured by using isotopes for ex ampl h a y water The a erag turno er i about 10% of the t tal body fat pe day

Adipose tissue Collections f ti e comp ed mai ly f f t a e called adipo e ti sues In additi n to fat they l o onta n pr t n and othe b t nces The m in sites of ad po e t ue are (1) beneath th ski (2) a ound th k dneys nd oth r o gan and (3) in th supporti g stru tu s of the intestines the oment m me entery It w f rm rly b l e ed that d po e t ues were *n ta* b l cally inactive but rece t work has h wn that they are s a t ve as or more a ti e th n most si gle types of ti sue For x mple they synthe i e fat *readily* f om arbohyd ate and oth r ur mate rial In add ti n they esp nd to hormo s such a n l n and gr wth ho m ne in ome in m ce m re than the t s ue ch a the l er or mu le This metab l c act ty re d n th p ote p rti n of ad p e t e rather th n n the fat it elf

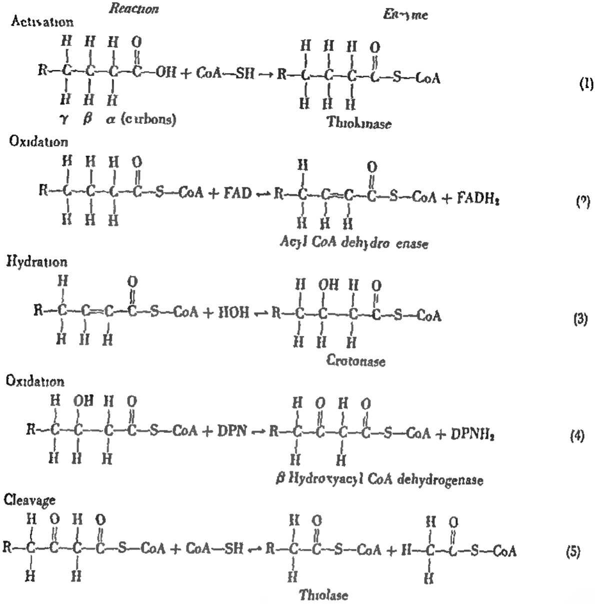
Oxidation and synthesis The body is able to x d ze fatty c ds for pu po es of ene gy pr duc t In ld t n it an synthes ze new fatty acids fr m p ec rs d r ed fr m rbohydr t o pro te n This b osynthesi s c lled l p gene s F Ly *en* in est gations ha e m de th re ct ns of x d t n and l pogen s l ar Th ubject i best nd t d by o de i g id t n f i

Oxid tio f high f tty acid The comple e ct o of idati n nd l p g nes s a mad po bl by oe zym A (CoA) wh h a omp nd f ad n mon ph phate (AMP) two m le les of pho ph te nd a mplex nitr gen deri i call d pa tother

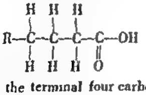


Coenzyme A

CURRENT CONCEPT OF FATTY ACID OXIDATION AND SYNTHESIS



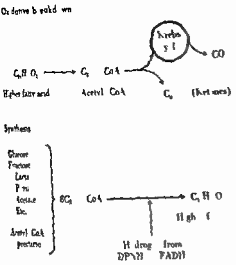
There are five reactions concerned in the oxidation of higher fatty acids. Each requires a special enzyme and two of the reactions require cofactors as oxidizing agents which accept the hydrogens from the fatty acids. In reaction (1) activation the fatty acid is written as



in which only the terminal four carbon atoms are given. R represents a chain of carbon atoms up to 14 in number. The initial reaction consists of activation by combination of the carboxyl group of the fatty acid with coenzyme A yielding an acyl coenzyme A. The enzyme is called the activating enzyme or thiokinase. In reaction (2) first oxidation two hydrogens one each are removed from the α and β carbons with the production of an unsaturated fatty acid analogous to crotonic acid. The enzyme is called acyl CoA dehydrogenase and the cofactor which acts as the oxidizing agent is flavine adenine dinucleotide (FAD). In reaction (3) hydration hydrogen and the hydroxyl group (from water) are introduced at the α and β carbons respectively; a β hydroxy acid is formed; the enzyme is crotonase. In reaction (4) second oxidation two hydrogens are removed from the α and β carbons of the β hydroxy acid to form a keto acid. The oxidizing agent is diphosphopyridine nucleotide (DPN). In reaction (5) cleavage acetyl CoA is split off. Thus a fatty acid two carbons shorter than the original one is formed. Simultaneously the shortened fatty acid combines with another molecule of CoA at the newly formed carboxyl group to yield a new activated fatty acid. The enzyme is β ketothiolase. The new activated fatty acid undergoes the same series of reactions and this process is repeated until the entire fatty acid molecule has been reduced completely to acetyl CoA. The fate of the acetyl CoA molecules will be discussed below. See DIPHOSPHOPYRIDINE NUCLEOTIDE (DPN).

The interrelation of oxidation or breakdown of fatty acids and synthesis is shown in the diagram

METABOLIC SCHEMA FATTY ACIDS



Oxidati n of the h gher f tty ac d uch palmitic d with 16 arb n atom yi ld ight m lec l of c tyl CoA Two fat s f a tyl CoA f rmed n th l e ar of immed at nterest

1 Oxid ti n th ough the K eb ycl to carbon d x d Th K bs ycle t a c mplex v t m f nzymes The zymes t r e of r a t o c mpl t ly x di e ac tyl C A t a bon d d m s ch fa h that th y le r tituted for f rth x d t n

2 Conde sati n f tw mol c l s f a etyl CoA with th pl tt n ff of th C A f m ng o- all l k e bod s *S* KREB CYCLE

Lipog ne The pr ces of y th of the high r f tty c ds f m n n f tty ac d p e u r is ul t ated n the low r h lf f the diagr m Wh n gested t m a bohyd te h as gl co d fru to e y eld imple ub t n es u h l ctic c d pyru i a d and et c d These pot t l precur s f t l CoA In dd t n p t also y ld t l CoA p ecu Th enzym A mole les th f rmed are u d t bu ld p th high f tt U t l h t tim ago th proce f y th s f th h ghe f tty cid t c s d ed t b th r er of th re ct o d scus ed de o d t n Th am nzyme a d th s m f t w a med t b n l ed x pt that th e t p d d n the oppo t d ect n Fo f tty d nth two r q r m ts h d t be m t (1) A p c f a tyl CoA s neces ary th se a e l t d n th d g m (2) A r d t n nm t (hyd gen) n d ed t l d d t du ed fl e ad n d leotid (FADH) d d ed d ph pho- pyrid (DPNH) n eded FADH d DPNH f m h hyd th t e d ati n f two etyl CoA m lec l n th red t atm ph r l d t th f rm t n f th fi st h gh fatty ac d (C) n th es n m ly butyryl CoA

F rth r d t n l d tep by step t l ld g p f th f tty id mole l by th mam malia h er t a chain containing 16 or 18 carbon Wh n the fatty acids reach thi length the acetyl CoA i plit off by an enzyme deacyla e yielding the free fatty acid wh ch in t rn c mb ne with gl c rol t f rm the triglyceride th at i fat

Recent re earch w rk in fatty acid synthe i has led to th conclu n that ynthe i of fatty a id requ res a c enzyme triph phopyridine nucleo- t de in the reduc d state ($TPNH_2$) whe ea oxi dati n req ires FAD *See* TRIPHO PHOPYRIDINE NUCLEOTIDE (TPN)

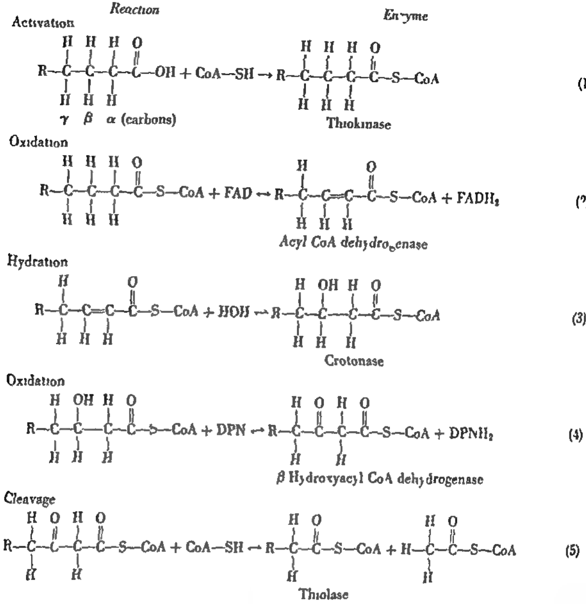
Change in length of fatty acid chains Th fatty a id in the b dy fat depot are comp ed of h ains wh ch alway c nt in an e n numter f arb n at ms The e fatty id contain the higher n m b r of arb n atoms nly namely 14 16 and 18 these are re pecti ely myri ti palm tic and te- ar c acid The body readily lengthens or h rten the ha n o th t if palmiti acid (C) s fed it is p ble to h w (u ng ot pe) that the palm ti acid i lengthened by two carl ns to teari ac d (C) Con r ely it i al o p ble to h w that t ar c c d (C) may be hortened to palmitic cid (C) or myr ti acid (C) Sh rter fatty id su h a butyric (C) cap oic (C_6) caprylic (C) and capr (C) a e f und n b tter fat but n t in th d p ts of b dy fat

Unsaturated fatty acids formation A fatty a id conta i g a double bond betw en two ca bon i c lled un aturated f tty a d Tran form tion f om sat r ted t un at rated f tty acids cur n the an m l b dy For xample te ric cid (C) a atu ated fatty ac d i r adily conv rted to ol c d w th the me n mb r of carbon atom but nly on d ubl bond The po iti n of th double bond i ind ted by the terminol gy $\Delta^{9,10}$ Th s mea n th e fol c a d that d uble bond exi t b tween the nth and tenth rb n o nt ng f m the rboxyl nd of the l ng fatty ac d chain Th ev s tran f rm t o f u at ted fatty ac d t atu at l fatty c ds al o o u the a mal body

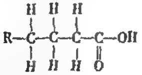
Essential fatty acids The an m l b dy is nca pabl of i t od i g a ond do ble b nd int a fatty a d It ha be n ob r ed th t if an anim l u h s a at s d pr ed f certai fat oluble itam u h as v tam n A D E and K t de- lop t iti nal d f ie c es ch racter ed by ha g s in th sk n nd imp ment f f rt lity Th se defic nc es can b cur d by feeding m ll am t f l nole c d n un t ated f tty acid with two d uble b nds Other un atu ated fatty d ch as l l n a id w th th ee doubl b nds d ach ido c with f r d uble bond e l ff t e S n th un atur ted f tty a ds annot b ynth e i ed by the mal but mu t be ing ted i fat f m eg t ble u c they are k wn as th ent l f tty ac d

Transport of fatty acids Unde ert n ond tio f t tran port d f om dep ts t th l e f for the metab lic rea t on They ar c rr ed i the blood stream h fly a t iglycerides but n dd tion may e t as f ee fatty id th c ll d

CURRENT CONCEPT OF FATTY ACID OXIDATION AND SYNTHESIS



There are five reactions concerned in the oxidation of higher fatty acids. Each requires a special enzyme and two of the reactions require cofactors as oxidizing agents which accept the hydrogens from the fatty acids. In reaction (1) activation the fatty acid is written as



in which only the terminal four carbon atoms are given. R represents a chain of carbon atoms up to 14 in number. The initial reaction consists of activation by combination of the carboxyl group of the fatty acid with coenzyme A yielding an acyl coenzyme A. The enzyme is called the activating enzyme or thiokinase. In reaction (2) first oxidation two hydrogens one each are removed from the α and β carbons with the production of an unsaturated fatty acid analogous to crotonic acid. The enzyme is called acyl CoA dehydrogenase and the cofactor which acts as the oxidizing agent is flavine adenine dinucleotide (FAD). In reaction (3) hydration hydrogen and the hydroxyl group (from water) are introduced at the α and β carbons respectively. a β hydroxy acid is formed; the enzyme is crotonase. In reaction (4) second oxidation two hydrogens are removed from the α and β carbons of the β hydroxy acid to form a keto acid. The oxidizing agent is diphosphopyridine nucleotide (DPN). In reaction (5) cleavage acetyl CoA is split off. Thus a fatty acid two carbons shorter than the original one is formed. Simultaneously the shortened fatty acid combines with another molecule of CoA at the newly formed carboxyl group to yield a new activated fatty acid. The enzyme is β ketothiolase. The new activated fatty acid undergoes the same series of reactions and this process is repeated until the entire fatty acid molecule has been reduced completely to acetyl CoA. The fate of the acetyl CoA molecules will be discussed below. See DIPHOSPHOPYRIDINE NUCLEOTIDE (DPN).

The interrelation of oxidation or breakdown of fatty acids and synthesis is shown in the diagram

condit n of maln tr tion is called cachexia See Lipid [w c s]

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Lipostraca

An o de f the ub l ss Br n h opoda erected by D J Sc urfi ld fo the M ddl Devo an fo il *Lepidocaris hyni nsis* Thi o gan sm was mall blind, and an nh b tant f fresh water It re em bled p ese t-d y a o tracan in some d ta l but differed in other d ta l f r exampl it had bi ramous antenn trunk append ges lacked gills a d th first tl pa were mod fied f r f edi g her a th remain ng appendages w re adapted f r swimm ng S B ANCHIOPODA [C B C]

B b iog aphy D J Scourf ld O a new type f cru ta an fr m the Old Red Sand tone (Rhyn e chert bed, Abe deen h re) *Phil T ans Roy S c Lond* Ser B 214 153–187 19.6

Liquefaction of gases

Liqu fied ga.es ar u ed n indu try in vari us military pe ations nd in e t fi r ar h Al th gh th l rgest ut l zation f uch l qu d s by th teel chem al and r frige at on ndu tri s th mis l devel pm t prog ams have r c ntly acc u ted f r a i c e i gly ign fic nt hare of the ann l prod cti n Relat ly small am nt f the ri l quefied g r ed in c nt fi n est gat ns pr m ly f r t bli h g low t m pera u e o ment in wh h tud e at temp a tu es bel w amb t may be c rr ed out S e CRYO-GENIC ENGINEERING CRYOGENICS GAS

Sev ral p c es ha e b devel p d f r lique fying ga e Alth ugh gn fi a t d ffe en es n effi ency e t am g th m d ffi ulti c t red in ed cing th m re ffi nt t pr t c h m d them all ughly omp t t Co qu ntly t h e of th r fr ge at ng y l to b s d f liq f ct n f g n g s t mad la g ly th ba f o n en e l l ge ndu t i l l quefac ti n pl t howev gn fi nt ed t n i p o-d n n t may b r l zed by use f th m e effi nt y le Th h s p d d an nti fo imp i g th t l f th e y les w th the res lt th t h gh p ty pl nt des gn e n w u ally b ed p n th m st ffi i nt thermo-dy m p oces

Alth ugh ny th m dyn m p oce s wh h re-ult a l w g f th t mp rat uld i p pl b t l ed n th l quef ct on f som g ly f h f nd p a t l empl ym t

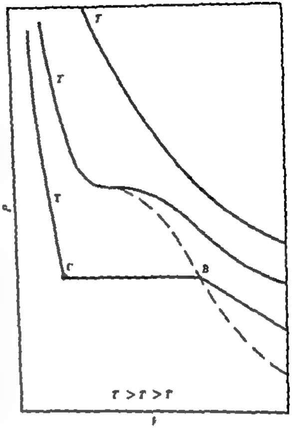


Fig 1 P s u e- ol me (P V) diag am f a typ cal gas.

The e are n o d r of incr a ng c mple ity ap r compr i n u e of refrig rator to c ol the g at on tant p e sur u t l l qu fa t n c r ut liza ti n of th adiabat c pe form nce of w rk by the g s in cy l c proce s with r gene ati e c ling and u of the Joul Th m n pr ce s in a cycle with ege er t n cooli g Combi ations of these four proc s es ha e al ften been found eff cti e

Vapor compression In orde t l q efy any gas by mpress n t mperat re must be below its c iti al t mper t re a r qu m nt f r t rec gni d B Thoma Andrew (1863) The p oces of vapor mp es i n can be m st ea ly elucid t d with the h lp of the p essu e l me (P V) d agr m sh wn Fig 1 n wh h several typi l is therm are plotted The upper o e f a tempe ature n exc s of the rit c l temp ratur T > T h w that a the gas is omp es ed the pre u e ri s mono-t nically with chang f ph e n m tter h w m h the g s i e mpr ssed The T = T i otherm di ides th P V d gram such that t c tant tem p r tu e below T and at certa n defi ite pres-ure and lume f ea h is th rm (the locu f thes nt l es n the dott d urve f r exampl point B) o further in e n in pre r with de n a ing l me r rved In t ad a l qu d ph e p og es ly f rm with d a i g lum until t p t C th yst m l quid Further de f the l me then leads t a sharply r ng f e of the p es r d to th mu h m lle com

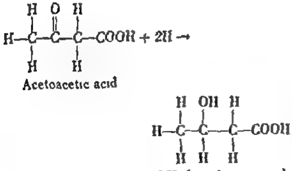
nonesterified fatty acids (NEFA) Fatty acids are also transported in the blood stream combined with phosphatides It is possible that the process of mobilization of fatty acids from depots may be under hormonal control A hormone *adipokinin* originating in the pituitary gland is stated to be this fat mobilizing hormone Under certain circumstances an excessive amount of fat is mobilized from the fat depots and transported for deposition in the liver Inadequate control of diabetes is one such circumstance The feeding of certain substances such as choline prevents this accumulation of fat in the liver Such a substance is called a lipotropic agent If the diet is deficient in choline the animal develops a fatty liver Methionine is also a lipotropic agent and when it is fed prevents the accumulation of fat in the liver It has been shown that methionine transfers its methyl group to β *ethanolamine to form choline The reaction is*

$$3CH_3^- + H_2NCH_2CH_2OH \rightarrow (CH_3)_3\overset{+}{N}CH_2CH_2OH$$

Methyl (from methionine) β Ethanolamine Choline

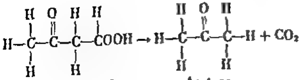
This process is called transmethylation

Degradation of fatty acids Liver muscles and other tissues can break down the fatty acid portions of fats to smaller molecules This process of oxidation is called β oxidation because the second or β carbon counting from the carboxyl group is oxidized As a result the fatty acid chain is shortened by two carbons forming acetyl CoA In the muscles and other organs acetyl CoA is further oxidized by the Krebs cycle as already described *but in the liver under certain circumstances all the acetyl CoA formed is not oxidized Instead* two molecules of acetyl CoA may form acetoacetic acid which cannot be further oxidized by the liver Acetoacetic acid is transformed into β hydroxybutyric acid or acetone according to the following reaction



Acetoacetic acid

β Hydroxybutyric acid



Acetoacetic acid Acetone

These three compounds are called the ketone bodies They are formed only in the liver Under certain circumstances such as starvation or diabetes these acid derivatives of fat are formed in *excessive amounts in the liver and accumulating* in the blood give rise to a condition known as ketosis or ketoacidosis The excessive formation of ketone bodies leads to a high concentration of them in the blood a condition called ketonemia In addition excess ketone bodies are excreted in the urine leading to ketonuria Such ketoacidosis in the patient if allowed to continue unchecked results in his death Before the advent of insulin such fatal acidosis in diabetics was quite common It is to be noted that the muscles are capable of oxidizing the ketone bodies and deriving the major portion if not all of their energy therefrom in starvation of diabetic ketosis However in the uncontrolled diabetic *subject the formation of ketone bodies may greatly* exceed the utilization of them by the muscle or other tissues so that fatal ketosis results The excessive ketone formation in the diabetic is due primarily to an inability of the diabetic to synthesize fatty acids from carbohydrates or other sources This failure of lipid synthesis is believed to be basically due to the inability of the liver to metabolize carbohydrate in a normal way Oxidative formation of fatty acids to ketone body exceeds fatty acid synthesis ketosis therefore results

Uncontrolled ketosis in the diabetic patient brings about abnormal acidity of the blood *dehydration due to excessive loss of fluid* and loss of sodium In consequence the patient lapses into coma

Role of the phosphatides The phosphatides are compounds of phosphate and certain bases containing nitrogen *namely ethanolamine serine and* choline the so called *phosphatide bases* When combined with fatty acids they tend to make the insoluble fatty acids soluble in water They also tend to congregate at membrane surfaces and so are found in higher concentrations at the surface of cells They are not found combined with fat in the depot but can combine with the lipids of the blood and of the liver

Obesity The daily energy requirements of the body are met by the caloric yield of the food intake If more food is ingested than is required for energy demands the excess is converted into fat and deposited in the fat depots Long continued *ingestion of food beyond the caloric requirements* leads to the excess deposition of fat or obesity There are some physiologists who believe that obesity is due solely to overeating but others believe that certain individuals have a type of metabolism *which leads to fat deposition even when the* caloric intake is relatively small

Cachexia In certain conditions such as chronic infectious diseases cancerous or other malignant growth diabetes hyperthyroidism an excessive loss of fat may occur leading to emaciation and diminished fat stores of the body Such an extreme

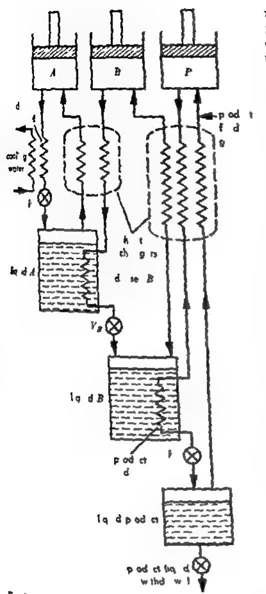


Fig 3 G lq f ct by d f p c m- p n f g t

h th t ha g t d t occ rr p ally th t is, adi b t lly d ev r bly Th m a th t th ch ng n qu st m t h t d ut n ch a w y th t n h t h ge t ke pla e b t een the b t n nd its s und g d th internal f te d g t p od th h ng r t ll time b l n ed by e pr di g e ter l f es th t t th gh t th ha g the ystem em qu l b m l p a t h pr e ses b pp x m ted but t lly r l d Th t p p oc m t oft n t l ed f g t d l q fi b f r cycled g is the eve bl f l t p f ga Th ad b t q me t m y b t fied r l t ly ly by t d m thod f th rmal lat n well a b t g th p oc to oc ur s rap dl th t th nt t m l ble f r tra f r f he t fr m r d g to th s b t e. A

re er il le expa ion f a gas from a high t a l w pre ure can be appr x mated with either a pi ton or turbine-typ expander The f rmer has l een the mo e w dely t ed the latter alth o igl tl e m re efficient handle ich large vol mes of ga in propor on t t ze th t it devel pment and actual u e ha depended upon the need f r large producti n fac l tie for l quef ed ga es In addi tion w de pread u age of l oth type f expanders l as l en retarded until recently by la k of uital le meth d f lubri at on f r m ing parts and l ear ings at ery l w temperature I rd r t maint in the high the r t cal eff cien y inherent in th type of cycle h at generat on by fr ction i these ex pa der m i t l e minimized l ecau e all tempera ture incre e produced l v a g en am nt of he t r u ually appre iably larg r at l w temperatur s than at high

The mplest type of refrig r ting mach n em ploying th bo e principle i the gas ref g rator h wn n Fig 4 In an actu l mach e of the type sh wn expansi n f ai fr m 40 to 1 tm pre sure wh n th gas temperat r t the expa der int ke i 200 K r sults in n exit temperature f b ut 100 K In pr n ipl this refrigerat ng ma h uld l s rve a a liq efier f r the w rk ng fl id If the xpander were ad quately i lat d t tem p ature wo ld fall progr s ely with co ti ed operati n and eve tu lly the gas w ıld l qu fy in th e pand r it If Such a proces highly in ffi ent howev l ec u e the liq id f rmed w t the wall f the cyl nder tu bin This f l tate he t flow f m the hot cylind r wall to th w k g ui ta ce and introduces d l le r r b l ty int the y le In add ti n the forma t n f l q d i the xp nder ually nt odu e i s mechan al in tab l ty Hen e i p ctic th p nder a e u d o ly to p oduc the l w t mp atu e requ s t fo l quefact n The p o-

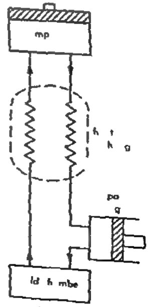


Fig 4 Sch m tc fl w d g m f g f g to

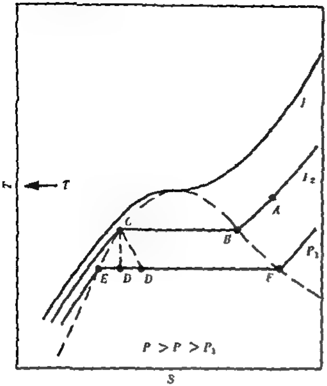


Fig 2 Temperature-entropy (T S) diagram for a typical gas

pressibility of the liquid Assuming the critical temperature of a gas to lie above ambient liquefaction of a gas by vapor compression consists simply of compressing it *isothermally until it liquefies*

A procedure whereby a liquefied gas at a temperature below ambient can be produced using a vapor compression process is best described with the help of a temperature entropy diagram for a gas *In Fig 2 the decrease in entropy S with temperature T* for a gas held at constant pressure is shown by the various curves labeled P_1 P and P (*see* ENTROPY) At some temperature less than T for every pressure less than P (for example point B) liquid will *begin to form at constant temperature* with further decrease in volume and continued withdrawal of *heat from the gas Let it now be* assumed that the vapor has been entirely compressed to a liquid (path $A \rightarrow B \rightarrow C$ in Figure 2) *If at point C the confining pressure that is the* vapor pressure *on the compressed liquid is in* excess of atmospheric pressure the liquid can be isolated thermally from its surroundings and the confining pressure slowly reduced The liquid will then *boil but due to its thermal isolation the heat* of vaporization can be supplied only by the sensible heat of the liquid itself The whole liquid is therefore cooled at the expense of vaporizing a part of it On the *T S diagram* Fig 2 this result is illustrated by the *path $C \rightarrow D$ assuming the pressure* reduction is carried out slowly and hence quasi reversibly For such an isentropic expansion this *diagram* provides a direct determination of the remaining amount of liquid The fraction of gas produced is given *by the length ratio FD/FF* that for the liquid is *DF/EF* In practice the expansion *of the compressed liquid* is carried out irreversibly through a valve Under the e *conditions a larger* fraction of liquid is evaporated as shown by the path $C \rightarrow D$

When refrigeration is the objective of the process outlined above (which is frequently the case) the gas formed *in the throttling stage as well as that* originating from evaporation of the cold liquid is returned to the compressor intake and the cycle just described is repeated By balancing liquid evaporation due to heat leak with liquid production by *expansion steady conditions can be* achieved in the low temperature reservoir Refrigerators of this type are useful in the liquefaction of still other gases If the cold liquid produced is withdrawn as product and used elsewhere a lique*faction rather than a refrigeration cycle is the re*sult Make up gas in an amount equivalent to that liquefied must then be continuously introduced to the cycle at the compressor intake

Refrigeration When the critical point of a gas *lies below ambient temperature a refrigerator can* always be used to cool the gas sufficiently to liquefy it by the vapor compression process described above Refrigerators are also employed to precool *the feed gas in other liquefaction cycles* producing *thereby a more nearly reversible* and hence more efficient process Because not only different uses but also many types of refrigerators exist the particular one chosen for any given application always requires a careful matching of process re*quirements to refrigerator characteristics In this* section therefore it will be possible only to outline the basic aspects of gas liquefaction using refrigerators

In any refrigerating machine with gas stream flowing from high to low temperature region and conversely it is necessary to prevent the circulating gases from transporting heat energy thus *introducing large and undesirable heat leak* into the cycle By using a device called a heat ex*changer heat energy can be transferred across the* medium separating the gas stream in such a way *that the warm stream is* cooled and the cold stream warmed over essentially the same temperature interval while ideally no heat energy flows along the *temperature gradient of the exchanger A simple* heat exchanger consists of two concentric copper tubes through which countercurrent gas streams flow with heat being transferred across the copper surface adjacent to both streams

*A particularly simple refrigerator is a continu*ously replenished bath of a liquefied gas boiling under reduced pressure and hence at a lower temperature than ambient as described in the previous section By using several of these baths each boiling at a lower temperature and each acting *in turn* as a condenser for the one with the next lower boiling point a cascade type *liquefier* may be assembled as illustrated in Fig 3 See REFRIGERATION

Performance of external work The maximum possible cooling effect resultant from any spontaneous change in the state of a substance obtai

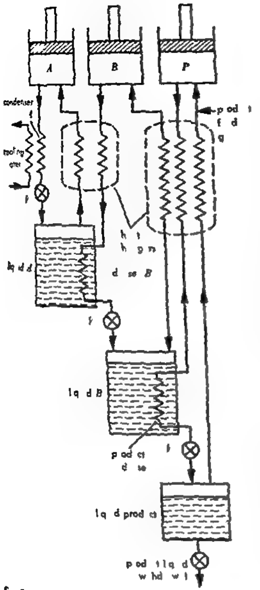


fig 3 G lq f ct by d f vap c m p ion f g t rs

res r ble e pan io of a ga from a high to a low p e sure c n b e approximated with either a pi t n or turbine type expander The former ha been the mo widely u ed the latter altho igh th more effcient handle such large volumes of ga in ▪ oporti n i its ize that its de elopment and actu l u I a depended upon the need f r large pr duct on facilities for l quefied ▪▪ ▪ In addi ti n w de p ead u age of both types f expanders has bee retarded until re ▪ tly by lack of su table m thod of lub icati n for movi g part and bear ng at ery low temp ratu es In rd r t maintain the high theoretical efficiency inh rent i thi type f ycle heat g ne ati ▪ by fr ction in the e ex pande s must be min mized becau ▪ all t mpera tur ne e e pr duced by a gi en amou t f heat are u u lly appreciably l rger at low temperatu es than at high

Th implest typ f refrigerating ma h ne em pl y ng the ab ve pr nciples i the gas r fr gerat r sh wn in Fig 4 In a actı al mach ne f the typ hown expan on f air from 40 to 1 atm pre re when the ga temperatu e at the expander ntake s 200 K esults in an e it temper ture f ab ut 100 K In p cipl th s ref g ti ▪ mach ne c ▪ lso rve s a l qu fer f th w k ng fl id If th xpander we dequately ▪ ulated it tem p tu e w uld fall progres i ly w th continued op r t o nd ev ntually the ga w uld liqu fy in the xp nde t elf S ch a p oces i h ghly in effi nt h wev r becau e th l q d s f rmed wets the walls of the yl nde o t rb ne This fa il tates he t flow from the h t cyli der wall to th w rk ng ub ta ce d nt oduces c ns de ble i e ▪ b lity i t th cy le In add tion the form t on of l qu d th e pa d u ally ntroduce er u mecha cal in t bil ty He e, n pra tice the exp nd r a e ed only t p du e the l w temperatures requi t for liqu fa tion The pro-

wh n th t cha ▪ s au ed t e ur i ntr p ally th t ad b t lly a d ev ibly Th s mea th t the h ge n q st n mu t b arri d ut n su h a way that n h t x ha g t ke pl ▪ twee th b t e d t arr d ng nd the int rnal f t d ng t ▪ d e the l ang t ll t mes bal n d by p d g t rn l f tces th t thr ugh ut th h g th vst m r m i ▪ q l b m In p a t u h p e e an be app m ted b t n r a tu lly e l d The i nt ▪ pr m t ften ut l ed n ▪ fr g r t d lti fi b f ycl d gn t the bl ad b t p i n f g Th ad t t eq m nt m y b t fied l t ly ly by nd d method f th rmal n l ti w ll s by a g th p s t ce r so ap dly th t th e uffi t t m l bl f t a f f h t f m rrou d g t the b t n e. A

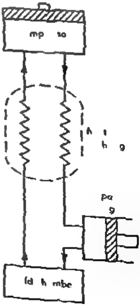


Fig 4 S hem t flow d g m of g f ig t

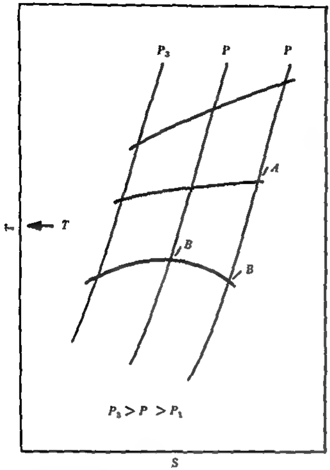


Fig 5 Temperature entropy diagram for a gas (high temperature region)

duction of the actual liquid is always carried out either by vapor compression or the Joule Thomson process Discussion of the latter is reserved until after the next section but an application of the principles developed so far is illustrated by the A D Little hydrogen liquefier In this compact device the working substance helium gas circulates through two reciprocating expansion engines operating at two different temperature levels The exit temperature from the lower temperature engine is maintained at approximately the boiling point of hydrogen The hydrogen gas to be liquefied is cooled by passing it through a heat exchanger counter to the expanded cold helium until its temperature is reduced sufficiently to permit liquefaction by vapor compression

Joule Thomson expansion Under certain conditions an irreversible adiabatic expansion of a gas (or a liquid) through a throttling device such as a valve can result in a decrease in temperature of the effluent gas A thermodynamic analysis shows that in this process called a Joule Thomson expansion the heat content or enthalpy of the gas is unchanged If the temperature at which the expansion is carried out is above a particular temperature for each gas the gas effluent from the throttle valve will be warmer than that at the valve inlet below this temperature called the inversion temperature expansion will result in a cooling of the gas In order to use this cooling effect in gas liquefaction the expansion temperature must always be below the inversion temperature The list shows the inversion temperatures of a number of common gases

Gas	T_i K
Helium	51
Hydrogen	205
Neon	242
Nitrogen	621
Argon	723
Oxygen	893

from which it will be noted that neon the hydrogen isotopes and the helium isotopes are the only gases not below their inversion points at ordinary temperatures Precooling before expansion is necessary only with these three gases in order to obtain refrigeration from the Joule Thomson process In Fig 5 a simplified T S plot of a typical gas is presented On it is shown the variation of S with T for three different pressures The heavy lines represent constant enthalpy lines and hence display the temperature history (as well as the entropy history) of a gas in an isenthalpic expansion Above the point marked T_i it is seen that a Joule-Thomson expansion always results in a temperature rise no matter what the initial pressure At T_i and here only for very low pressures for example point A there is no change in T upon expansion Below T_i there is a drop in the temperature upon expansion first at very low pressures and then with further decrease of the temperature at increasing pressures (path $B \rightarrow B$) At low tem

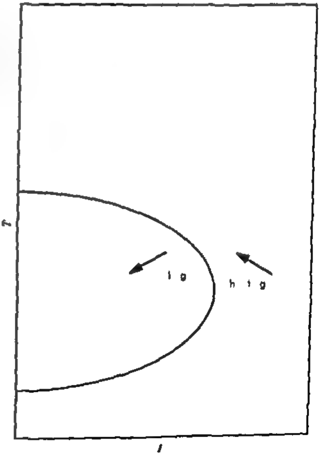


Fig 6 Inversion temperature versus pressure for a gas

peratures, the p ure at wh ch c ol ng occurs po pan gain decrea e. If the e tempera tures at hich the inversi n occur are plotted against the p ure ghly p rab lic curve s h h n Fi 6 is obta ned Expan ion from any p int withi the pa abola always produ ces cooling From a point outs de a heating occurs in ti lly n til the press re and temperature f the ga is redu ed uffic ently bring it with n th parabola.

In considering this process for g s l q efacti n it must be m ti ned that at lea t until the expa so m de t occ r t ery low tempe atures the Joul Thomson process a f r le s effecti e cool ng process than i entropic expan on By cycling the gas cces ely thr ugh a compres or heat exchang and an e pan i n al howe er the cooling btained f om the pa ag of each ma s f g thr gh th alve can be m de umulat e In th a the t mp t re f the exp n on val e s continu ly ed ced unt l finally eno gh refrigerati n p oduced to liquefy a fracti n f the in it ga. B epa t g th liquid and returning th emaind the compre s r thro gh the he t exchange th te f cool ng of the expan on alve begins t dec and e entu lly a teady st t re hed at which the refrig ration emoved as liquid j t balances th t prod ced in the expan i n. In F g 7 th s steady tate is represe ted on TS diagram. The atio DG/LG is the fraction of

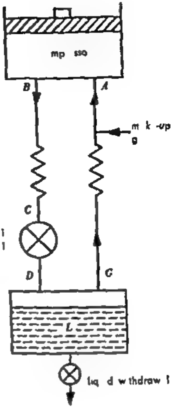


Fig 8 The L d g s l q f ct cy le

liquid pr duced per m le f gas pas ng th rough the Joule-Thom n alv the fr ction DL/LG repre ents moles f gas ret rn ng to the compre so at wh ch po t make up ga is added to the ystem an amount neces ary to maintain steady st te ond tions th o gh ut the cycle The g e t att act n of the J ule Th ms proc s its lack f m vi g p rts at l w temperatures Fu thermore it pr d a sat factory method f p duci g the l q id and sepa ting it f om the gas stream as co tra ted with th p iously ment o ed d fficul ties e ou t r d when th l q id i allow d to f rm in a tu b ne r e pan ion ng

The J ule-Th ms n p e is ed in many d ff nt way in the pract ce of gas l quefacti n Th mplest s that fi t de eloped by C rl von Linde sh wn in F g 8 The l tters attached t the draw g orr pond to th tate of the g as h wn n F g 7 In pract e g pu fi r m t be introd c d d wnst eam of th comp e s in rder to pr nt nd n ibl imp rities f m cl gg g th he t e hang r Th bas cycle h been ad pted in ma y way of wh ch few (1) use of an expan n gine po mp s on or a gas f ig t ool th f ed t th Joule-Thom n al e (2) u f indep nd t h gh nd low p e e c its with w thout additional p ec l g and (3) use of cl ed r u t r f g a ti n w th l q efact n by h t ha ge with th w k ng ub t n It ho ld lso be n ted th t the reve s bl p n n of the l qu d thr gh th ottl l me t o ed n th ct n n ap

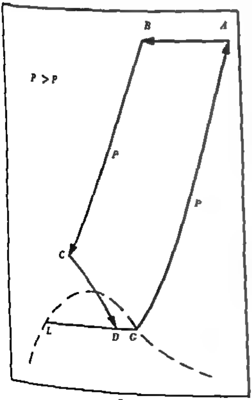


Fig 7 J le-Th mso l q f ct cy l f m ature- ropy diag m (h gh t mp t d two-phase reg)

compression is an isenthalpic or Joule Thomson expan ion

In the discussion of the four basic methods of gas liquefaction given above no association of a particular gas with one or more liquefaction schemes has been made This omission has been deliberate because with few exceptions all schemes will work with all gases and therefore as mentioned earlier the choice of method is governed by other considerations

Storage of liquefied gases Liquefied gases at temperatures below ambient could be stored in definitely if it were possible to prevent heat influx to the liquid from the warmer surroundings No perfect heat insulators exist however hence heat constantly flows at a rate dependent upon the quality of the insulation into all such liquefied gas reservoirs If the container is vented to the atmos phere this heat leak causes continuous evaporation of the reservoir contents If the container is sealed the heat leak will cause the temperature of the liquid to rise with concomitant increase in the pre sure until either the temperatures of the liq uid and surroundings have equalized or until the increased pressure has ruptured the container Because sufficiently effective insulation is now available to reduce boil off losses to economically tolerable levels atmospheric venting is common practice in most large storage facilities Occasion ally however because of hazard value of the prod uct or liquefaction costs no loss storage of lique fied gases is required This may be accomplished for short periods of time by simply plugging the vent line and allowing the temperature of (and pressure in) the reservoir to rise For longer pe riod refrigeration at the temperature level of the liquefied gas must be supplied to balance the heat leak to the container

Liquefied gas containers range in size from tiny glass laboratory dewars for specialized studies with small amounts of rare liquids to reservoirs con taining hundreds of thousands of gallons for use in industry The insulation employed depends en tirely upon the proposed usage In a mi sile tank for example the storage time is short insulation can therefore be almost eliminated especially be cause minimization of propellant tank weight is a prime con ideration For storage of liquid helium however where reliquefaction is costly and the gas supply itself is not unlimited use of the best insula tion available is usually justified See ATMOSPHERIC GASES PRODUCTION OF [E F H]

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Liquefied petroleum gas (LPG)

A mixture of petroleum ga es principally propane and butane which must be stored under pressure to keep it in a liquid state At atmospheric pressure and above freezing temperature these sub tances would be gases Large quantities of propane and butane are now available from the gas and petro leum industries These are often employed as fuel for tractors trucks and buses and mainly as a do mestic fuel in remote areas Becau e of the low boil ing point (−44 to 0 C) and high vapor pressure of these ga es their handling as liquids in pressure cylinders is necessary Owing to demand from in dustry for butane derivatives LPG sold as fuel is made up largely of propane On a gallonage basis production of LPG in the United States exceeds that of kerosine and approaches that of diesel fuel

Operating figures for ga oline die el and LPG fuels show that LPG compares favorably in co t per mile LPG has a high octane rating making it useful in engines having compression ratios above 10 1

Another factor of importance in internal com bustion engines is that LPG leaves little or no en gine deposit in the cylinders when it burns Also since it enters the engine as a vapor it cannot wash down the cylinder walls remove lubricant and in crease cylinder wall piston and piston ring wear Nor does it cause crankcase dilution All these fac tors reduce engine wear increase engine life and keep maintenance costs low However allowances must be made for the extra cost of LPG handling equipment The LPG must be stored in relatively heavy pressurized tanks and special equipment must be used to fill the fuel tanks on the vehicles See GAS TURBINE INTERNAL COMBUSTION ENGINE PETROLEUM PRODUCTS [M SO]

Liquid

A fluid which flows under exceedingly low shear stresses and which conforms to the shape of a con taining vessel but which lacks the capacity to ex pand indefinitely Above their critical tempera ture liquids are indi tinguishable from den e gases and it is possible to devise an infinite num ber of paths by which the transition from a liquid to a gas may occur continuously Ordinarily the range of pressure and temperature over which the liquid state exists is intermediate between that for solids and gases For substances wh e triple points lie above 1 atm pressure however the liquid state is stable only at higher pressures

Structure of liquids For normal sub tance the liquid is formed from the solid at the melting point by the absorption of the latent heat of fu i n Gen erally the density of the liquid state i slightly lower than that of the solid and melting i accom panied by an increase in volume A relati ely small number of substances in luding i e b i muth gal lium germanium and silicon c ntract on melting No sati factory explanation of the proce of melt ing exists largely becau e of the inadequacy f the theory of liquid Liquid like soli po e s vapor pressure which depend up n the tempera ture (see VAPOR PRE SURE) and b il when the vapor pre ure is equal to the ambient pre ure The energy ab orbed in the liquid vap r pha

change of one mole of liquid is called the molar latent heat of vaporization and the value in calories approximately equal to 2 times the absolute temperature of the normal boiling point (Trouton Rule) In the gaseous state there is complete randomness in the spatial positions of molecules relative to one another and to good approximation at low vapor densities there is a negligible intermolecular potential energy By comparison the atoms, ons or molecules in the crystalline state occupy definite positions on a three-dimensional lattice and approach perfect order in the details of their arrangement in space Except for the relatively small kinetic energy of vibration of atoms about their equilibrium positions the energy in the solid state is entirely potential The mathematical theory of both the gaseous and solid states is well developed because of the mathematical simplicity resulting from complete randomness in one hand and complete order on the other Liquids occupy positions intermediate between gases and solids ... the ideal structural regularity of crystal Molecules in the liquid state experience strong forces of attraction and repulsion but have nevertheless sufficient thermal kinetic energy to move about ... independently of one another As a result, the theory of the liquid state must necessarily be very complex and generally is rigorous theory ...

The mathematical difficulties of an exact theory of liquids are prodigious although much has been accomplished by the efforts of M. Born, H. S. Green, J. E. Mayer and John G. Kirkwood Approximate theories have been ... from the one of two points of view (1) a model which represents the liquid as a dense gas and which attempts to calculate the thermodynamic properties from the interaction of molecules, and (2) models which treats the liquid state as an approach to the crystalline state in which a certain degree of configurational disorder has been introduced.

Studies of the structure of liquid metals, fused salts, organic liquids ... which ... of the liquid ... distance ... The short-range order ... similar to that observed in a crystal but extend only a few atomic layers ... distances The long-range order ... of the crystalline state is completely missing Diffraction patterns ... a few maxima and minima ... in the ... density and analysis of the pattern ... the probability of ... as a function ... distance ... between a ... It ... possible to calculate ... in the liquid ... the ... of the liquid which ...

sult is that of a time-blurred imperfect approximation to a crystal

Liquids vary considerably in the nature and strength of the forces responsible for cohesion In molten salts which are excellent conductors of electricity and are completely dissociated into ions the forces are predominantly coulombic Liquid metals which are also excellent conductors consist of positive metal ions and electrons which are quite free to move in an electric field The condensed rare gases as well as liquid nitrogen, oxygen and hydrogen and nonpolar organic liquids owe their cohesion to van der Waals forces (see GASES) These forces are comparatively weak and of short range and the boiling points of such liquids are accordingly low Dipole-dipole forces are responsible for much of the cohesion in polar liquid In water hydrogen fluoride and organic liquids containing molecules with hydroxyl groups hydrogen bonding is responsible for relatively high boiling points and low vapor pressures See MOLECULAR ASSOCIATION

Properties of liquids The inability of liquid to withstand shearing stresses under their viscous flow properties Viscosity varies widely among liquids and diminishes exponentially with temperature in all cases in which structural changes are not occurring One of the most interesting of all liquids is liquid helium produced by Joule Thomson expansion of helium gas which has been cooled below its inversion temperature Liquid helium boils at 4.19 K and is a normal liquid having however an unusually large zero-point energy When further cooled it undergoes a remarkable change into helium II at 2.19 K The latter is a quantum fluid possessing exceptionally low viscosity (about 1/100,000 of that of water) It appears to possess about the same degree of order as solid helium and is the ... of great interest ... the theory of liquids See BOILING POINT; EQUILIBRIUM, PHASE; LIQUEFACTION OF GASES; MELTING POINT; SOLUTION; SUPERFLUIDITY; SURFACE TENSION; VISCOSITY OF LIQUIDS [N.H.N.]

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Lissajous figures

Plane curves traced by a point which executes two independent harmonic motions in perpendicular directions the frequencies of the motions being in the ratio of two integers (see HARMONIC MOTION) Such figures produced on the screen of a cathode-ray tube are widely used in frequency and phase measurement

Methods of constructing Mechanical, optical and electronic methods may be used to construct Lissajous figures Blackburn pendulum ... of one ... pendulum hung from another with their two axes of rotation at right angles The Lissajous figure traced by the bob A ... example of an optical method is afforded by a beam of light reflected successively from two small mirrors each

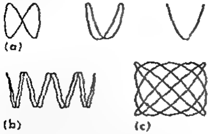

Fig. 1. Typical Lissajous figures for ratios of vertical frequency to horizontal frequency of (a) 2:1 with various phase relations; (b) 8:1; (c) 5:4. (From F. E. Terman, Radio Engineers' Handbook, McGraw-Hill, 1943)

mounted on the prong of a separate tuning fork; the forks vibrate in perpendicular directions, and the image of the light source, focused on a screen, traces out the figure.

The cathode-ray oscilloscope furnishes the most important and practical means for the generation of the figures. The x deflection plates of the tube are supplied with one alternating voltage, and the y deflection plates with another. If the frequencies are incommensurable, the figure is not a closed curve and, except for very low frequencies, will appear as a patch of light because of the persistence of the screen. On the other hand, if the frequencies are commensurable, the figure is closed and strictly periodic; it is a true Lissajous figure, stationary on the screen and, if the persistence is sufficient, visible continuously as a complete pattern. See OSCILLOSCOPE, CATHODE-RAY.

Frequency measurements. Measurement of frequency in sinusoidal wave motion (for example, in alternating electric current) may be accomplished with an oscilloscope if one of the alternating voltages is derived from a variable-frequency calibrated oscillator. The standard is adjusted until a stationary figure results. If f_v is the frequency of the signal on the vertical deflection plates and f_h that on the horizontal plates, then f_v/f_h equals the number of times a side of the figure is tangent to a vertical line divided by the number of times the top or bottom is tangent to a horizontal line. The shape of the figure depends also on the relative phase of the signals (see Fig. 1), and in the case where one half of the figure coincides with the other, the rule just stated does not hold. This situation is not troublesome in practice because unavoidable slow frequency drifts of the signals prevent the figure from being exactly stationary; instead, the shape of the figure changes as though the relative phase of the signals were slowly changing.

In some cases the standard is of fixed frequency and the unknown is nearly equal to the standard (or to some multiple or submultiple thereof). The figure will drift slowly through the various aspects it can assume for the nominal ratio involved. The actual ratio can be obtained from the nominal ratio and a correction determined by the rate and direction of drift of the figure. This method is particularly valuable for the intercomparison of standards.

Phase measurements. These usually involve two signals of the same frequency. In this case the Lissajous figure is an ellipse, of which the shape and orientation depend on the relative phase and relative amplitudes of the signals, as shown in Fig. 2. The relative phase θ is given by

$$\sin \theta = \pm B/A$$

in which A is the maximum half-height and B is the intercept on the y axis. Figure 2 shows how the quadrant in which θ lies is determined by the orientation of the major axis of the ellipse and the direction of motion of the spot. If the latter is unknown, the resulting ambiguity amounts to that in the sign of $\sin \theta$, once it is decided which signal is the reference. The ambiguity can be resolved by shifting the phase of either signal in a known direction and noting whether the phase shift indicated by the figure increases or decreases.

The most precise comparison can be made when the ellipse degenerates into a straight line. This condition is therefore used as a null in measurements made with a calibrated phase shifter. The

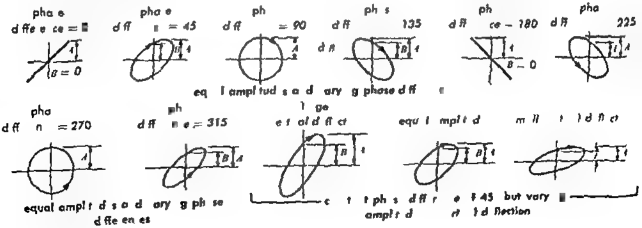

Fig. 2. Typical Lissajous figures of 1:1 frequency ratio. (From F. E. Terman, Radio Engineers' Handbook, McGraw-Hill, 1943)

unknown ph se h lt d tu hs th ll d the cal brated phase h ft resto es it

More compl ated figu es a e employed in th calib t of pha e hifters A ignal at the de ired frequen y i e ected th ough the ph shift r t the y pl tes f an oscilloscop a d 'so thro gh a f equency m lt plie to the x plates If the f que cy multipl t on is 8 for e ampl th Li ajo s fig e will appe as i F g 13 The phase hifter i then uc es ely set t th n po t for which one-h lf of the fig re co ides with the other these p tions w ll correspond t pha d ffe ence f in th ca e π/8 S PHASE ANGLE MEASUREMENT [M GR]

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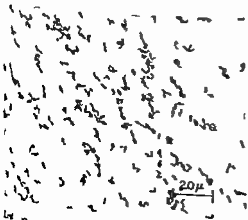
Listenosis

A disease f man d animal au ed by a mall gram-posit e ba ill *Listeria mon cytogenes* Th mi roo gani m, membe of the family Cory nebacteriace e h been olated from man d 27 spec es of a im ls and birds i 30 cou tries from th Arcti to the Tr pi s The ep dem logy is n t understood

The o gani m m sur s 0 5 by 1–3 μ Small rod with ro nd d end predomi at shown g palisad form u n and short cha s Y ung b oth cult es di lay char cteri tic tumbl g m t lity G wth n ampl medi is e h n ed by e ri hme t w th blood or gl c e. There re f ur se otypes (se IMMUNOLOGY)

Listenosis i animal t kes many forms uch s meningoencephalit in wine goats and sheep distemper like d a e in d gs a d fo es ge eral ized infection in rabb t and gu e p gs with fo l liver necro d ma ked m ocyt si Abortio with ext n i f t l nec o i may occ i rum nan su h as cattl

Li t ri in man occu s prima ily a m ni git or gra ul m t inf nti ept c with h gh f t l newborn m rtal ty and n ros Septic m l co m n (SEPTICEMIA)



Lis o nocytog

Diagnosi depends on i lati n of *Listeri* from appropriate clinical pec men Ide tification i certain if a pure cult re in tilled i to the rabb t c n juncti a produces e e keratoc juncti itis An aggl ti at on titer of er 1⁄160 patients erum i diagnostically signifi ant

Treatm nt hould be based on in vitro a tibi ti se siti ity te ts on the train isolated *Se* BACTERIOLOGY MEDICAL CORYNEBACTERIACEAE EPIDEMIOLOGY [R W R]

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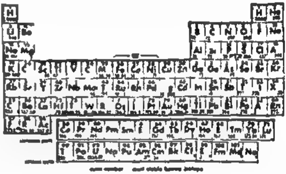
Lithium

With n atom number of 3 a d an at mic weight of 6 94 l thium Li stand t th head f the alkal metal family i group Ia in the periodic table of th eleme ts Lith m in nature i a mixture of the two i otopes Li a d Li Much of the commer cially proces ed l th um in the U ited State has been subjected t isotope sepa tion in the nterest



of obta ni g the p re lighter ot pe of lithium Li The l ght l thi m i t pe plays n important ole n therm ucl pr ces es Lith m a ail ble in the m ket may thu ha e a n d ably differ ent at m c weight becau of the remo al f the l ght i t pe It i th l ghtest ol d el m nt, a d a ft l w melti g r e metal In ma y f its physi l a d h mi l p p rti it resembles the alk l e-ea th met l i gr p IIa a m ch as, m e than t d es th alkal m tal fam ly f whi h it a membe

The lem nt wa fir t d co e ed b J A A f ed n Swed n dur g ct a lys of p t lite Th m tal wa first lated by S H mphry D vy i 1818 by elect olysi

Uses The maj r d str al s of l th um in the f rm f l th m te as a th ck ner f lu b cat ng gr e Lithi m ba gr s c mbin h gh w t r st n w th h gh temper tur t a d g d low temp atur p ope tie The all p po e grea es epl e a m lt t de of pec alized gr s s nd th y ha e capt red ab ut e-th d f th tot l t m t g e ma ket A th imp rt t f l thi m c mp ds i e m pec fi lly i l n m l for m lat The maj ct of the l th um s

flux. In ceramic mixtures, lithium carbonate readily undergoes the reaction

$$Li_2CO_3 \rightarrow Li_2O + CO_2$$

yielding the Li_2O as one constituent of the oxide mixtures of which most ceramics are composed. Alternatively, lithium aluminum silicate ores can be used directly.

There are a number of lesser uses for lithium and its compounds. Lithium hydroxide is used as an additive to give longer life and higher output in the alkaline storage batteries known as Edison cells. Lithium chloride and fluoride are used in welding and brazing fluxes; lithium-copper and lithium-silver alloys are used as self-fluxing brazing alloys. Lithium perchlorate has been suggested as an oxidizer for solid propellant rocket mixtures; it offers a higher percentage of available oxygen than any other perchlorate due to the low atomic weight of the lithium.

Occurrence. Lithium is a moderately abundant element and is present in the earth's crust to the extent of 65 parts per million (ppm). This places lithium a little below nickel, copper and tungsten and a little above cerium and tin in abundance. In sea water there is about 0.1 ppm of lithium. It is found in human and animal organisms, in soil, in mineral waters, and in plants such as cocoa, tobacco and seaweed. Its presence in the sun's atmosphere has been established.

Although lithium occurs widely in nature, the concentrations in ores are generally quite low, unlike sodium and potassium whose relatively pure halides may be mined or pumped from brine wells. Lithium resembles rubidium and cesium in its manner of occurrence as part of complex silicate minerals. Lithium ore assays are usually expressed in terms of per cent of lithium oxide, Li_2O, and 1.0% of Li_2O affords a commercially processable ore. Most commercial ores run from 1–3% Li_2O; virgin ores rarely contain as much as 6%. In North America the most common lithium ore is spodumene, which generally occurs in pegmatite formation in association with feldspar. The largest known reserves are in the King's Mountain area of North Carolina, in Quebec, and in Manitoba. Substantial quantities of lepidolite and petalite occur in Africa, particularly in Rhodesia. Amblygonite, the other commercially important lithium mineral, is found in Europe, Africa, and South America. A nonmineral source of lithium is the brine in Searles Lake, California. Table 1 lists the important lithium ores.

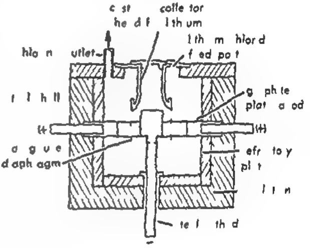
Table 1 Commercially Important lithium minerals

Mineral	Simplified formula	% Li_2O theoretical
Spodumene	$LiAlSi_2O_6$	8.03
Lepidolite	$LiKAl_2F_2Si_3O_9$	4.09
Petalite	$LiAlSi_4O_{10}$	4.89
Amblygonite	$LiAlFPO_4$	10.10

Metallurgical extraction. Lithium ores are concentrated from 1–3% Li_2O to 4–6% Li_2O by heavy media separation using dense nonaqueous liquids and by froth flotation. The silicate ores, which are those processed most widely, are then chemically cleaved by acid or alkaline processes.

In the acid process, spodumene ore is first heated in a kiln to about 1000–1100°C to change the naturally occurring alpha spodumene to beta spodumene, a more friable, less dense crystal form which is readily attacked by the acid. The ore is then roasted in a second kiln with an excess of sulfuric acid. Water leaching of the kiln product yields lithium sulfate, which is treated with sodium carbonate to give lithium carbonate. The carbonate is converted to the chloride by reaction with hydrochloric acid.

In the alkaline process, spodumene or lepidolite ores are ground and calcined with about 3 parts limestone to 1 part lithium ore at 900–1000°C. Water leaching of the kiln product yields lithium hydroxide, which is converted to the chloride by reaction with hydrochloric acid.



Cross section of lithium cell.

Dry lithium chloride is the feed material for the manufacture of lithium metal by electrolysis. The cell bath is a fused, molten mixture of lithium chloride and potassium chloride. The cell is operated at 400–420°C with a voltage across the cell of 8–9 volts. The current consumption in electrolysis is about 18 kilowatt hours per pound of lithium produced. The illustration shows a typical lithium cell.

Thermochemical processes for the manufacture of lithium have been studied but have not been applied commercially.

Physical properties. The physical properties of lithium metal which make it attractive for many of its present and potential uses are summarized in Table 2. (The values cited are those available; there are many values in the literature which disagree with them.)

Noteworthy among the physical properties are the high specific heat (heat capacity), large temperature range of the liquid phase, high thermal

Tabl 2. Physic l propert f l thi m met l

Prop rt	Tempe at e C	F	M t ic (sc ntific) u it	B t l (en ee i g) n ts
Den ty	0	68	0 531 g/cm	33 lb/ft
	400		0 490 g/ 3	30 6 lb/ft
	800	11	0 4 g/ m	8 6 lb ft
M lt ng po t	1 9	3 4		
Boiling point	131	103		
Heat f f	1 9	3 4	103 l/g	186 Bt /lb
Heat of apo zat	131	103	4680 c l/g	84 0 Bt /lb
Viscos ty	00	39	5 6 m ll po ses	13 1 k t t
	400		4 0 m ll po ses	8 k t c t
	600	111	3 17 mill po ses	6 k t u t
V po pressure			0 8 mm	0 01 lb/
	10		91 0 mm	1 (lb/ n
Therm l co d t ity	16	4 0	0 109 c l/(sec)(cm)(m)(C)	6 5 Bt /(f)(ft)(F)
	539	100	0 0 3 al/(sec)(cm)(m)(C)	1 6 Btu/(f)(ft)(F)
Heat capac ty	100	1	0 90 cal/(g)(C)	0 90 Bt /(lb)(F)
	300	57	1 0 l/(g)(C)	1 0 Bt /(lb)(F)
	800	11	0 99 l (g)(C)	0 99 Bt /(lb)(F)
Elect cal res t ty	0	3	1 34 m rol m-cm	
	100	1	t m rol m-cm	
Surf ce te n	00–500	39 93	Abo t 400 dynes/ n	

d t t l w c ts a d y l w de ty Lith um m t l sol ble n l q d n m a a d s lghtl soluble in th l w r liph t c m es b t eth l m ft n ol ble in hyd oc l There a p bl hed d ta n the lub l ty of lith m met l i m lt n in g n lt

Chemical properties Lith m u d g es la e umber of ct o th b th o ganic a d nor ganic re g ts

Ino ga c t ns L thi m rea ts w th xygen to form the m n xide Li_2O d the per x d Li_2O_2 The pe d LO i n t known nd may t ex t ber use f insuffi e t o m fo tw g n tom arou d the m ll l th um at m

Lithi m i the nly lk l m t l that rea t w th nitrog t oom temp tu e t fo m a tt d Li_3N wh h s black

Lithium cts adily w th hydr g n at ab ut 500 C t f rm l th m *hyd ide* LiH Of ll the alka m tals, l th m act mo t r ad ly w th hy dr gen, nd i the nly lk li met l form ng h dnd t bl e gh t be m lted witho t de compo i n An mportant r act n of LiH that th b ff id diethyl ether at BF (C_2H) O to y ld d bo an B_2H_6 r l th m b r hyd id LiBH

Th re t n of l th m m t l w th wate i ceed gl g r L th u re t d tly w th carbo to f rm th ca b de LC_2 L thium om b nes r dily ith the h loge t l at d tem per t es, f rm hal de w th the em f light. Lith m doe t bu n chl n nl b ed, d i f t nly perfi lly w th l qu d b m p mably b u e f the f m t n f r stect h l de t gs

W h mm l th m r ct t form th m d LiNH Th t n m y b rried ut by h t g l h m t m f mm a at 400 C, o b t n th l qu d mm r n th p e f

taly t ch s i n On h ting the am de l es amm ia t form th imide L_2NH l thi m i th nl alk li met l which f rm an m de

Lith um and carb n mo ide re t t giv l th ium arbonyl $LiCO$ rather un t bl pr du t

O g ni e ct o s Whil lithium d n t r t with p affin hyd b n t d es und rg add t n e tion w th a yl ted alkene a d with d e Th add ti n of l thium t d en sy tem i the b i for the t l ti p l me at n of d e es t ynthetı el tom ha ing atur l r bb r prop e t es O e rec ntl d el ped y thet c r bb m pl y l th m m tal d pe ed i pet ole m jelly th at l t t polym p ene t s p ly o- p e th ex ct tr t r l u terpart f n tur l he a r bb f om *H a b asil e s* (rubbe tre) L th m al o rea ts w th etyl nic m p u d r pl ng th a etylen hyd g n t m a d f rm g lith um cetyl de wh ch a e major t ti th synth i f v t m n A

Lithi m metal e ct w th alc h l f m ng l th um alk de LiOR nd l berat ng hyd g n Alk x d f m les e dily w th l thi m th n they d w th d m a d the mm ci l til ty i m h le tha that of th sod m lk x des

L th m dd t rb yl mpo nd u h aldehyde a d ket n g i l thium add tion mp nd a nte med ate whi h an be hydro- lyze l to n l h l Simil ly ga l th m m d add t ld hydes d k tone ing dd n p odu t whi h y eld alcoh ls upon hydrolysis O ga l thi m mpo nd eact with o n c cid t add t o pr d ts wh ch an be hyd olyzed t ket e thi t n u ed n ne step of th t m A y th

Lithi m n al be sed n ju ct o with m m i r am nes t eff t niq red ct of ar g c mp nds f e ample the re d t f omat hyd a b t m ool fin

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Bibliography: R. N. Lyon, *Liquid Metals Handbook*, 2d ed., Navexos P-733, 1954.

Lithosphere

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Lithosphere, geochemistry of

The study of the distribution of the elements and of their isotopes in the lithosphere and of the processes, both past and present, which affect this distribution. The lithosphere contains more than 99% of the mass of the earth. It is therefore by

far the most importa t exerv nt f almo t all f th chem al leme t and the p oce s in th lithosph e exert a dom nant nflu nce on many n la phe mena

Kno ledge f the di tribut on of the elements and of their i t pes in the l th phere is ery uneven Almost all of th ampl s wh h ha e a tu all been lyzed ha e come fr m th pre ent urfa e of th earth r f om a depth of le than 8 kil meters (km) S nce the a rage rad us of the arth is 63 1 km analyzed ampl s repr ent only scrat hi g f om the o term t porti n f th gl be The evid nce fo the chemical compo ition of th earth bel w the 8 km level s theref r la gely i d rect and mu t b ba ed on the d ta f geoph i s and inf rred f om meteorite an ly s Th mass a d l me of the e rth are k wn and theref its a ag den ity On the basis of tra el time curves f r arth waves generated by earthqu ke a d man m de e plo ons c nvinc ng mod ls of the changes with d pth in the d nsity and in the locity of mpr ional and hear ves an b con t u ted These d ta tog the with nf rmati o th magnetic f ld of the earth a d th mech ni l and thermal p pert s f the earth c ntribut t th f nd f informat n u ed in truct g th pre ntly a epted mod l f r the chem l t ucture of tho e porti n of the e rth h h cann t be observed d r ctly Se SEISMOL OGY

The d ta n the hemi al omp tion of meteorites c mpl ment the geophy al data The m del based on geophy al d ta a d th e ba ed on meteorite d ta re p i glv m l a d pre ent epts f th maj r feat res of the chem stry of th rth int r r almo t rt lw rect f the maj element

S h a degree of ert inty c nn t be la m d f r m t of the mi o el m nt F we th n 10% f the h m al element a nt fo r 98% of th ma s f th l th phe e Th abund e f th m j rity f the element n the l thosph e i th ef well bel w 0 1% Th ad a ces in trac lem t a aly i i 19 0 h p ed th t d f th d trib t s f elements p e nt n rock n m nt les than 1 part pe million (ppm) n 10⁻⁴ th t the geo hem try f these el m nt n the pp r f w kil met m f the lithoph e r bly well k wn H wev geo- phy al t h qu n t suitable f h t d s th d p part of th rth d th e of m teo t dat alw b t by th un ert nty g td ng the mp o tl at th re neces a ly l e pond b tw en the ab nd n e of l m t n th al zed m t r tes nd i th rth nt r r

Chemical compos tion of the crust Analy es n mbe ing th t f th a d h be made n geol g m t i l All n ly all f the ly ed amples h m f om th ru t of the rth that from abo th M h r d c t i wh h l es n d pth f abo t 30–50 km nd th nt nt d at a d pth of ab ut 5–10 km under the oceans Altho gh many f the chem ical analy s are of omewhat qu estionable ac curacy the large mas f a ailable chemical data is amply sufficie t to gi e an accurate de cription of the a erage compo ition an l of th compo i t nal vari ti n of the various types of geologic m t ial This information can l e mi ned with data on the relati e abundance f the arious rock type in the upper portion of the earth s crust to give a fairly complete description of the a erage chemical c mpos ti n of th di ectly acces ible parts of the litho ph re

Some data on the ch mical ompo itio n of vari ous ediment and rock types are reprod i ed in the accompanying table A comprehen i e tatement of all the elements in each geochem cal pha e i gi en elsewhe e See ELEMENTS (GEOCHEMICAL DISTRIBUTION)

One of the m st tr king aspects of the data i the r lati ely mall range of chem cal compo i tion i the upper part f the litho phere Th ame do en r element p ed m nate in all f the maj r sed ment and ro k type All of the e except the carb nate rock c ntai rough ly b t een 40 a d 75% silica SiO Th carb nate rocks a e al m t always cal m o c l ium m gne i m c r bonate often c nt ning an dmi t i of s li e us mater al The rustal abundances of th major le ments and al o of the min elements therefore d not depend in v ry t tic l way n the r lati e pr port ons a gned to the v ri u sed m nt a d r k type n the e rth s cru t Neverthele it ho l be rem mbered that the cr tal abund n es l sted in the table a d in Figs 1 and 2 m t be re- g ded as er ges s bje t to revision

The cru tal abundan e data h been pl t ed on a l ne r scal in Fig 1 nd on a logarithmic cal n Fig 2 The fi t plot emph zes the fact of th pr po de nce f ert n l the el m nt of low atomic numbe N leme t w th atomic num be greate than 6 pre ent in the earth cru t with an ab nda ce greate than 0 1% The loga r thm c plot f F g 2 perm t th epr s ntati n f the b ndanc f all of th n tur lly o curring lem nt nd empha zes the fr q ency of cru tal ab nda c l es betwee 10 ppm (10⁻³%) and 0 1 ppm (10⁻) p rticularly among the elem nts of h gher at m numb r The bro d f atures of these f gures a now r a o bly w ll unde stood Th y a e the produ t of th pro s es of el ment f rm tion of the proces s op ting du ing the f rmati n of the rth d of th p o es s w th th arth wh h h ve p rated b th the di ec n of hom g n zat n and d versifi t on of the hem al c mpo t on of th various p rts of the rth S e ELEMENTS (COSMIC ABUNDANCE) ELE MENTS AND NUCLIDES (ORIGIN)

Chemical composition of the mantle Th ea th mantle con ts of mat ri l between th M h o d ontinuity mark ng the ba e of the rust nd the di nt nu ty at a d pth of 2898 km ma king the limit of the arth s o No nequi cal iece of m ntle h s ev r been

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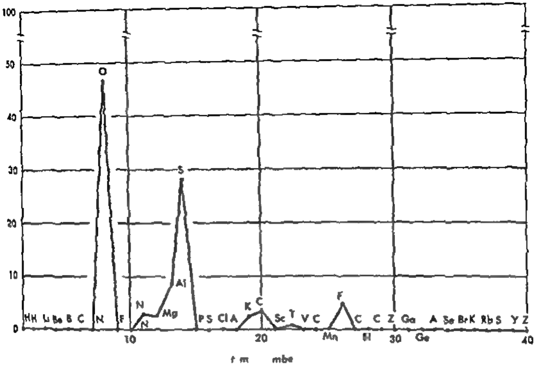

Fig 1 Cru t l b d f l m ts f t m mbe 1–40

this i d tt ctly p obable b t that th a e atom mbe f re mater al t les tha th t f iron. S lic n h s th fo bee uggested as a importa t t tuent f the e but al oth alt rn ti es ar t lea t p ble d the p obl m rem in pe at th t m

Exc pt fo th minor elem t d ta from th me tallic ph e f meteorites th i f rm tion as r g rds the min r eleme n the re m l ly scanty

Important crystalline phases The maj r po tio of th *l tho phe* m l d In th crust the solid s e p ed m ntly well ry t ll z d nd th is alm t c rt nly true f r the m tle as w ll *Or g n a d* l on a th m t al und t le ment in th cru t d the ma tle a d th s l d ph ses e lm st all *e the o d s* l cates Since th proces desc bed b low depe d t a co d rabl e tent n the pr pert es of th m po ds th ery t l ch m try f th m j r m n eral ph es is b efly reviewed t th s p nt S e MINERALOGY

Oxide st ct es Th tru tu f m t of the rock f rmi *g o* des is mpl In all f them O the l rgest i n d d term e th t ct r l f me- ork In pericl s MgO the O io s a e ub lose packed a d the Mg cc py th octa hed ally oo d ated hole betw e neighb ng O ns I the p l gr up R R the do l t R ons a d the t i al nt R occ py e th t trahed lly ctahed lly coord at d h l betwee c b c cl e-pa ked O i s. H g n l l e p k g of O io s is f d in rundum Al O and n r l t d m n l h a lme *i F T O* nd ge k lte MgT O

In these tru t res the cat n g c upy 4- or 6 oordinated h les n the O f mew rk

Sil cate st uct es Th e tructures *e nor* m lly more compl cated than th o de t uct es Th b i u t of str t i the lic n-oxyg tet hedr S O ns ting of a S ion at the cent f a t t ahedro wh se c ne are oc cup ed by th ent of O io These tet hedr ns may be jo ned by cati s in the ol vines (Mg Fe)$_2$SiO zi co ZrS O or the g rn ts R (S O) In th st ctu es th [S O] group erve a f n t n im l t th t f the [SO$_4$] g o p in th ulfat The stru t of the ol ine s m la to th t of th spi els i fact l ne n ert to p n l f m t high p e su es

In the majority of l cate c mpo d th [S O] gr ps lymer ed S h p lymeri zati n m y lead t group of tw three ix tetrahed s to ffecti ely nfi te h n do bl h ins to sheet truct res to thr d me nal netw k f [SiO] gro p The phy cal p pe t es of s l t m eral ar ofte r l ted n a im pl m ne to the type of p lyme zat n f the [S O] gr p Th cle vag pla es f the py r enes the amph bol s a d the feld pa are p r llel t the effect ely fi t ha d ubl ch n char t tic of the e m eral groups Sheet f [S O] t t ahed o are par llel to th pr o ed lea ge of th m ca cl ys nd chlo rite g p m ls The unif rm three d m n n l n two k of q artz i flect d the la k of l av g th m l

The th impr bable f mulas gge t d f m y s l c t m ls by h m c l a alys be-

Average chemical composition of sediments and rocks

	I I	SO₂	TO₂	AlO	FeO	FeO	M O	MgO	C O	N O	K O	P₂O	CO₂	H₂O
Sediments and sed mentary rocks														
Calcareous sand oozes	1	188	03	∪1	38		01	11	390	0	0	0	?98	
Red cl y	2	5 8	09	161	90		10	29	~	1		03	16	
Silic ous oozes	3	555	05	1,1	58		0,	3	9	10	--	03	69	
Average pel igic sediment	4	85	■1	81	0		06	18	30∪	08	1	■	9	
Compo iti n of suboceanic sediments	5	13?	07	11(	16	06	03	1	-11	11	18	01	1	
Average ediment	6	115	06	109	10	0)	03	26	19	11	19	01	131	
Aver ig shale[d]	7	58 10	0 6	■ ■	4 0	4		- 44	3 11	1 30	3 4	0 1	63	5 00
Average sandstone[d]	8	78 33	0 ∪	4 7	1 07	0 30		1 16	∪ 0	0 4	1 31	0 08	5 03	1 63
Average limestone[d]	9	5 19	0 0(	0 81	0 54			8)	4	0 0	0 33	0 01	41 54	0
Average sediment[d]	10	∪79	0 ∪	13 39	3 4	- 08		- 6	89	1 13	86	0 13	38	3 -3
Igneous rocks														
546 granites 4	11	708	04	116	16	18	01	09	0	3	41	■		
137 granodiorites ■	1	67-	06	1 8	13	6	01	1(	36	3)	31	0?		
635 intermedit igneous rocks 13	13	∪19	1	1(7	33	5	0	38	66	4	3-	04		
198 basalts 19	14	199	14	160	54	65	03	(3	)1	3-	1	04		
18- ultramafic ■ocks 2	15	410	17	61	45	88	0?	- 7	10?	08	07	03		
Averag igneous rocks 11	16	601	11	1,6	31	39	01	3		39	3?	03		
Metamo phic rocks														
- ■ qu rtzofeldsp thic gneis es 50	17	07	05	115	16	-0	01	1		3	38	■		
103 mi a schists (1	18	613	10	1	1	16	01	7	1)	19	3	■		
61 slates 6)	19	618	0	1)1	33	∪4	0?	-9	10	1	38	01		
-00 amphibol te 68	0	03	16	157	36	78	0	(0	9	)	11	03		
Crust of the earth														
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Ba d on sum n ries l y A I oldervaart in *Crust of the Fa th* Geol S c Am Spec I aper 6 19 n l l y *B* Mason in *I rinciples of Geochemistry* d ed Wiley 19∪8

[b] Values omitted where sampl s were calculated water free

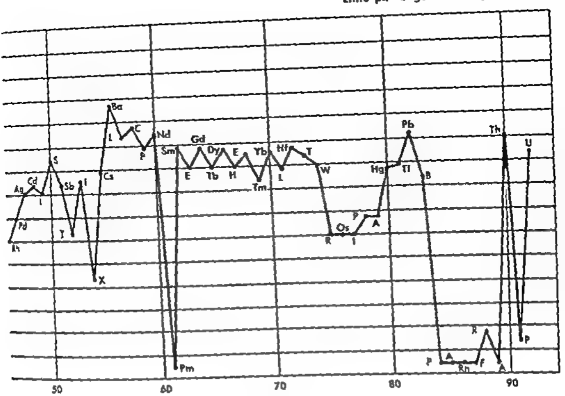
I rom Poldervaart fi ure of gi en r fers to index number as used in P ldervaart

[d] F m Mason

analyzed although the olivine bombs ejected from a number of volcanoes may well have l een derived from the mantle Pre ent thinking regarding the chemical compo ition of this portion of the earth is therefore l a ed almost entirely on ge phy ical evidence and on the circum tantial meteorite e i dence The latter line of evidence ugge ts that the composition of the mantle is not very different from that of ultramafic igneous rock (see index 15 in the table) the geophysical evidence ■ in sub tan tial agreement with this hypothe i H wever the evaluation of the density and elastic wave propa gation data ■ at pre ent rather tenu us since ol ervations on the tate of silicate minerals at tem peratures and p re sure characteri tic of the mid dle and lower portions of the mantle are still very fragmentary At pre ent it seem likely that silicon oxygen magnesium iron and calcium are in fact the major elements in the earth s mantle but the cry talline pha es in which they occur still remain to be determined It i al o very likely that the mantle at lea t in its upper portion i more heterogeneous than has u ually been a umed an l that it tructure may be almo t a complicated a that of the cru t

Knowledge of the abundance of the minor ele ments in the mantle i even more fragmentary than that regarding the major element Only in the ca e of the radi active element can something be said independent of the meteorite mo lel The al undance of the ■ elements mu t l e l w en ugh to pre ent melting of the mantle and thi mu t mean that the al undance of p ta ium uranium an l th rium must l e very much less in the mantle than in the crust In theory heat fl w mea urement can gi e more definite indi ati n al out maximum c ncen trations of the e element in the mantle However the c mplexitie intr duced l y radiative and p i l ly convecti e heat fl w in the mantle introd i serious complications int the interpretati n f surface heat fl w mea urement S e EARTH (HEAT FLOW)

Chemical composition of the core Th e re f the earth con i t of the material l etwe n a l pth of 2898 km and the center of the earth I r blem similar to tho e be etting the stu ly of th c mp i tion of the mantle al o limit study f th c re Again all data are circum tantial Th m te rit data ugge t a c ■ f metalli ir n with an admix ture f nick l Th geophy ical data in l at th t



t m mb

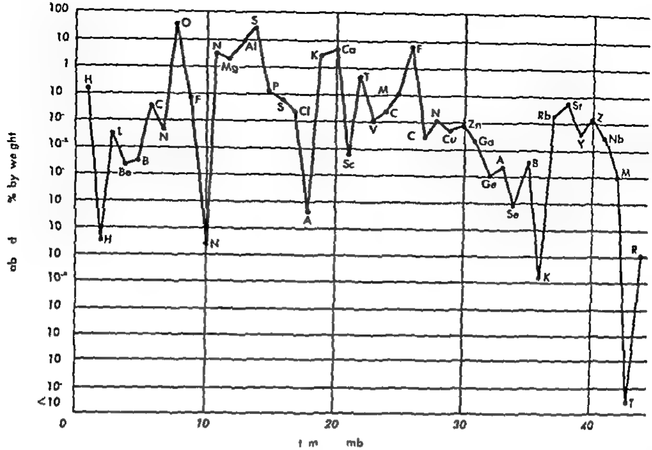
nt egion l re. rv r l al erv i de- m ded by many pr bl m For ta e n t dies f the ge of n ig eous ck unit th system of terest d idual ry t l f th m eral m n r l u ed fo dati g p p e The p obl m in ge ral terms thu e ns t f d termin g the event wh ch h e tak n pla e w th n the sy tem f terest and the e t t of exch ng b tw en th ystem a d t en nment Se ROCK (AGE DE TERMI ATION)

Cha ges n y tem are f ri u k nd C r ta n system p b bly ha e h ng d ath r l ttl in s ze a d mp t n d r ng mu h f earth h st ry Th co e of the rth may well b on ys- t m Other y t m h p ob bly grown te d ly thr gh t rth h t y The hyd o pher t l m t certa ly a c e n p nt and th e rth ust it lf m y well h c e d pp ec bly n l ume th xp n f the e th m ntl Still other y t m th bi ph f r o h e pr b bly ff ct t d app ably n olum d ring geol g c tim All f thes y tem r t l t part ally i t d pe dent s that th dy m f the e rth re ex eed gly c mpl t d and g n r lly d f fi ult t ed t m ble p port n

The major cycle M ny f these pr esses pa t p te i what h me t be k wn th m j r cy l wh se m t mp rt t a pect ar h wn in Fig 3 Th w ath r g f igneou sed m t ry and m tam rphi ock t th l tho phere- tm s- ph e bo d ry prod es ed m nt These ar b r ed d mp ted at d pth to p od ce ed me t ry rock At m e elev ted t mpe t o pres- re r b tf ed me t ry r k recry t lliz to met m rph cks At t ll h ghe temperatures parti l r ompl te meltu g m y prod e rock melt wh h ool t f rm gneou r ks Expo u of these r k to w athering pr sses th n renew th y l

We th ri g p o e es Th hem al d sequ lib- ium betw en the tm pher nd many of th r ck typ s e po ed t t s o e of th imp ta t fa ts of ge ch m stry The re t ns of hyd ation l ti n o dat n nd ca b nat on charact ri tic of the z ne f w ath r ng r pa t f th ontinuing pr s of the pp o h to equ lib um t the l tho- ph e-atm phe bo nd ry

The effect f th atmospher i e and gro d wat n ari us m n al d pend n the stab l ty n th typ of v nm t and on th rat at wh h u stable m ne als d pp ar in fa r of t ble ones Th feldsp rs pyr xe es and ol i e re am ng the m t re d ly destr yed rock f rm ng m n al I th s typ of n ronment, the remov l f the l rg r tions (N K Ca++ Mg++) is u u lly ap d d the remai m nerals re usually hyd ted lum n m s l c tes ont ning no e f these ati n o c ntai g them n ap- prec ably m lle tities th n the orig nal m ral Som un t bl r k f rming min rals act m h m l wly with the tmosph e M gne- tite F O s n of thes Th stabl ox de f n n equ l b m w th atm ph ric xygen i h m t te, Fe O y t magn tite a comm n c n tit ent f b ch sa ds ac umulate f the res due f w theri g p o es es Finally mi e als s ch as



F g 2 Crustal abundance of elements of atomic number 1–92

fore the advent of x ray crystallography were shown to be quite natural results of their often compli cated silicon oxygen framework structures and the development of the crystal chemistry of the sili cates has been one of the most significant contri butions of mineralogy to geology since 1920 *See* SILICATE MINERALS

Processes involving the lithosphere The earth is not at rest Earthquakes volcanism and moun tain building the three major manifestations of disequilibrium at depth are evidence of wide spread physical and chemical change below the surface of the earth Erosion and chemical weath ering are evidence for the pronounced di equilib rium b tween the atmosphere and the lithosphere Chemical changes are thus taking place at various levels in the litho phere and at the boundary be tween the lithosphere and the atmosphere bio sphere and hydrosphere The proce es taking place at the earth s surface can be ob erved di rectly and are therefore more completely under stood than the processes taking place within and below the earth s cru t Yet it is just the proce se at depth which are of primary interest as a key to the history of the crustal evolution of the earth

For most of the element the earth can be con sidered a closed or an almost clo ed sy tem The two major exceptions to this rule are hydrogen and helium which e cape at significant rates from the upper atmo phere Hydrogen e cape has prob ably played an important role in the evolution of the atmosphere from a methane ammonia arg n water vapor mixture to its pre ent highly oxidized state Minor exceptions to the rule are tho e ele ments which are entering the atmo phere as constit uents of meteorites or as co mic ray particles or which are swept up by the earth It eems unlikely that these additions have affected the chemistry of the earth materially

The earth can therefore l e regarded a an es en tially clo ed system consisting of a numler of re ervoirs The exchange between these re ervoirs may be appreciable and is often a complex func tion of time In times comparable to the age of the earth the mass and composition of various re ervoirs have changed radically The l asic problem in the tudy of the dynamics of geochemi try thu consi ts of defining suital le re ervoirs and of de termining the nature and the rates of the proce es which are operating on them today and which have done so in the past

The primary divi ion of the earth into the litho sphere hydro phere and atmosphere is con enient since the limits of the e reservoirs are rea onal ly well defined and their contents of apprecial ly dif ferent kinds The bio phere has a somewhat differ ent status since in space it o erlaps the other spheres completely The primary di i ion into f ur spheres is too coarse for many pr l lem in earth science The subdi ision of the lith phere into crust mantle and core is evidence of thi an l th further subdivi ion of the cru t into sediment and sedimentary rocks metam rphic rock and ig e u rocks was implied in the di u i n of t average chemical compo ition of material in these cat gories Further subdivi ion of these larg nit

66 1958 B M so Pri e pl of Geo h mist y 2d ed. 1958 A Muir (ed) Geochemistry pt. 1 1954 A P ld rvaart Cru t of the Earth Geol Soc Am Spec. Pap r 62 19–144 1955 K Ran kama a d T G Sah ma Geochemistry 1950 O F Tuttle and N L. Bow n Origin of G a ite in the Light of E p rim tal Studi s i the System NaAlSi3O8-KAlSi3O8-SiO2-H2O Geol S c Am Mem. 4, 1958

Litopterna

These we hoofed herb re confined to th Ce- o zo f South Am r ca The rde wa well ep- resented from th Paleocene to the Pl i tocene and ppa ntly m e on that ont nent from a on d larth a ce try By later Paleoc n t m two main li es f des ent were clea ly demarcated The *Pr t theri dae* (Fig 1) displ y d a rema k ble er l t n ry co e ge ce w th the hor es in th ir dentit n and in educt on of the lateral dig ts of the feet. The foot w s educed to a ingle med an toe by e rly M o en t me The member of the M crau h dae (F g 2) we e pr port n d m b a n th cam l a d by late T rt ary tim h d mila ly lo t the rt b al rt r al canal f the c rvi al ert b e They early dev loped a tend ncy t ard et cti n of the nasal bon by lat T rti ry time th n l open g w tu ted b e th e es top f the kull Th p taliza tion has been th ght to i d at the p es n e of a tru k r p rhap do lly tuated n t ls adapted l r bme ged amph bi i tenc Th re fun tion l d git emain n th feet f e e th m t d n ed m c u hen id S e CONDYLARTHRA

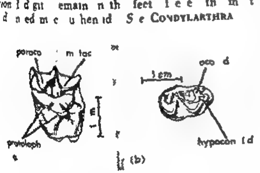


Fig 1 ( ) Upp r d (b) l w m l f P t the- ea ly M oc p t the d l t pt m f m th M Cru format f P t g A g t

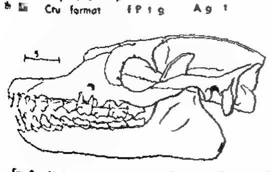


Fig 2 Sk ll nd jaw f Th d g H m n early M oc m cr h d l pt f m th So t Cru form f P t g A g t (Aft W S H 1910)

Both g oups hare the foll w ng characters l ld typ c l f r th order The kull wa witho t xpan on of the temporal or squamo al nu s as in the notoungulate a pc to bital ba wa present Den t tion wa primiti e w th full eutherian formula and a tendency to reduce inci rs a d pper ca n e teeth cheek teeth were unred i ed low to h gh-crowned the po terior premolar l ecoming m lariform The upper mola s we e q adrate the p racone and metacone were cres ent c the pro- toloph was pre ent but the metal ph ab ent The l wer m la were b r entic the ento onid was not olated but j i ed to the p te io nd of the t oth. The feet we e functi nally 3-toed or red iced to a gle digit the weight borne by digit three See DENTITION

The earliest known mammal an f una n South Am ri a (late Paleocene) ontained representa ti es of b th gr p of litopterns By Oligoce e a d Mioce e t me th litopterns ea hed their g eate t recorded *abu dance* The p oterotheres d d n t urv the Pl o e nd of th macrau he- n d only the large *Mac auch nia* rv ved until Ple tocene t me [B H T]

Liver

An organ cha a teri t f all the ertebr tes It i not found in other an m l however org ns of m lar funct uch the h p *topa creas* of cru ta e us exi t in in *ertebrat s* Th l er i an o g n z d mas of cells through which en u blood fl w as t return f m the *nte tine* t the h rt. It s co n ted with the test ne by y tem of du ts In the n rm l adult, t s t ble organ n that its c ll divide nly a ely and t c t hitec ture s fixed It is however an acti e orga the largest gl nd in th body and ha a l g numbe f f n t n Among th m t imp rta t fu t o f th l e re the to age of food tuffs ar d ta mi th l an f the blood b det fi atio nd ph gocytos th limin t n of wa t p d u ts th prod ti n of auxil ry digesti e sub- tances th destruct o or in t ati n f ho m ne the p od ct n f certain bl od pla ma mp e t d h m t p s the p od ti n f blood cell i the embryo

Th li e ece es a small amount of its blood upply d r ctly fr m th heart through the h p t c art ry b t th large p rt i recei ed from th wall f th gut th ugh th p rt l e n This l r g with t product f d gest n a d oth ubstan es ab- o l ed th ough th ntest l mu Th p rt l e n a d hepatic artery nt r the l er tog th r and both b a h epe tedly Th l n h s tr l ide by d w th m re branches of tl bil d ct and a lymph es el th portal ca l These a cont n l i o d f e ect e ti u kn wn a Gl so p ule In pl c of c p llari tl r are s mewhat l rg es l th in d with phago- yt K pffe ell thei wall Th inuso ds fi lly j n t f m the hep tic ns th t d in the l er nt th nf i vena a a The l r cell are r ged i d plates perme ted by th net

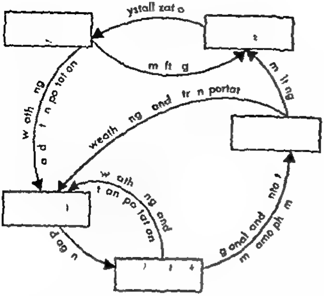


Fig 3 Important featu es of major geochemical cycle

quartz, SiO and calcite $CaCO$ are stable in the zone of weathering They will only dis olve in rain and ground water until the e waters are saturated with re pect to SiO and $CaCO_3$

The processes of weathering and transport thus alter exposed units of the lithosphere in the direction of equilibrium with the atmosphere but often do not reach this state completely *See* WEATHERING PROCESSES

Sedimentation and diagenesis The proces e which take place as sediments enter the oceans are complicated but normally alter their over all chemistry and mineralogy only slightly However evaporation in closed or partially closed basins can lead to the formation of evaporite beds of compo iti n very different from that of the normal detrital sediments Sequences of ulfates carbonate and halides formed in such environments are therefore inter persed with sediments c n isting largely of ilicates and oxides in tratigraphic columns of many areas The over all compo ition of these columns is then on the average appreciably richer in carbon dioxide water chlorine nitrogen sulfur and boron than average igneous rock This is not unexpected since CO and H_2O as well a g ologically important compound of the other elements are in a ga eous state at the temperature of rock melts and are undoubtedly l st preferentially to the earth s surface and incorporat d in ediments *See* EVAPORITE (SALINE) FUSED SALT PHASE EQUILIBRIA

After deposition most sediments become buried They therefore are subjected to higher temperatures and pre ures Under the e condition cementation a lo s of poro ity and a certain amount of recry tallization take place and and tone lime tones and shales (the major types of sedimentary rocks) are formed Such changes are perhaps mo t pronounced in the ca e of carbonaceous sediments Peat becomes dehydrated and pa es through the variou grade of coal approaching the composition of graphite with increa ing depth of burial *See* DIAGE E I

Metamorphism At temperatures and pre ures higher than those normally encountered in diagenesi important changes take place in the mineralogy and texture of mo t sedimentary rock These change are termed metamorphi m and lead to the formation of metamorphic rocks It is obvi ou that there is no harply defined boundary between diagenetic and metamorphic proce es *See* METAMORPHISM

Metamorphism may either be local in nature a in the vicinity of a body of intru ive igneou rock or it may be regional occa ioned by a rise in temperature pressure or both over a con iderable area Reactions in both contact and regional metamorphism are determined by the prevailing pres ure and temperature by the compo ition of the rock units and by the kinetics of the po ible reactions Understanding of these reactions has been increa ing especially ince the introduction of water as a component in systems studied in the laboratory and the investigation of material tran port during metamorphism Metamorphic reactions are apparently nearly i ochemical although the tran port of certain elements suggests that mall volume of rock undergoing metamorphism cannot afely be regarded as closed systems *See* SILICATE PHASE EQUILIBRIA

Melting and crystalli ation At still higher temperature melting of rock units begins The composition of rock melts depends on the comp ition of the parent material on the ratio of liquid volume to that of the solid residuum on the temp rature and pressure during melting and on the degree of equilibrium attained between the liquid and solid phases The liquid fraction may mo e into higher levels of the earth s crust and may even break through to the surface as lava or other volcanic products At the lower temperatures higher in the crust cry tallization normally takes place the nature of the resulting olids is determined largely by the initial composition of the liqui l an l l y th conditions prevailing during cooling With the aid of pertinent laboratory studie the relati n hip between many diff rent igneou ro k types from th highly silicic granites through the intermediate gabbros to the ultramafic perid tite and dunite have been satisfactorily e tabli hed alth ugh the major que tion of the origin of the bulk f the ili ceous rock of the upper crust i till larg ly u n an wered *Se* MAGMA

This que tion leads directly to the que ti n of the nature and extent of exchange b tween mantl and cru tal material and to the ex h ng f material between the core and the mantle H wever a l ng as knowledge of temp ratur i the mantle and core and of th behavi r and mov m nt of material in the mantle i a circum cril d a n is at present the di cu i n of these p r be low the ba e of the cru t i n t very fruitful

(H I H)

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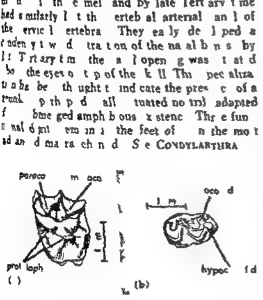
Litopterna

These w r hoofed h b vo es e nfined to the Ce nozo c f South Am ric The order wa well ep resented from the Paleoce e t the Pleistocene and app rently arose n th t ont ne t fr m a c n d larth an estry By late P leo ene time two m in lines of desce t were clearly d m r ated Th Prot therı dae (Fig 1) d played a remarkable ev lutionary n erge c with the h r e in their dent ti n a d n redu tion of the lateral d g t I th r feet. The foot was redu d t i gle m dian toe by rly M o e e time The memb r f the *M ra hen ida* (F g 2) w re p op rt ned m h i th e mel and by late Tert ary t me had s milarly l t th erteb al arterial an l of the ervic l ertebra They ea ly de l ped a t nden y t w d tra t on of the na al b n s by l Tertiary t m the a l open g was t at d b the eyes o t p of the k ll Thi pec aliza ti n ha be th ught t ind cate the pres c of a trunk p th p d all tuated no tril adapted f bme ged amph b ous x stenc Thr e fun ti nal d git em in i the feet of n the mo t ad an d ma ra ch n d S e CONDYLARTHRA



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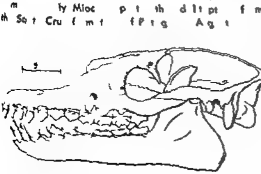

Fig 2 Sk ll d i w f The od *g n rum* ea ly Moc m h d lt p f m th So to C f m on (P goni A g t (Aft W S tt 1910)

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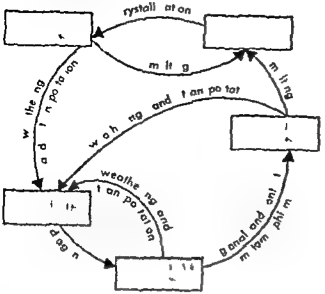
The e rliest kn wn m mmalian faunas in South Am rica (later Pale c n) ont ined rep e enta t es of both g oups of litopterns By Oligo ene and M o ne tim th l topterns rea hed the r gr ate t rec ded ab ndance The proterotheres d d n t s rvi e the Pli ene and f the macrauche ni d only the large *Macra h* urv v d unt l Pl to en t me [R H T]

Liver

An rgan ha a tert tic of all the ert b ates It is n t fou d in other an mals howe er o g n of mil r fun t n su h as th l p t pa cr a f cru t ceans e t in in rteb ate The li er an or g n zed ma s of cells through wh ch en u blood fl ws a it eturns f om the int t ne t the heart It c nected with the ntestine by a system of d ts In the n rm l adult it t bl organ in that it c ll d d nly arely and i vi architec t re is fix d It s howev r an a t e o gan the largest gl nd th body and h s a la ge number f fu t n Am g the m i mp rt nt f nct ns f th l e ar the stor of food tuffs and vit m s the cl n ng of the blood by d tox fic t n d ph gocyt s th elim nati n of wast p od u t the p od tion of au il ary dige t ub- t n s the destru t on r inact at on of h r m nes th p oduct on of ce ta n blood pla ma mponents nd h m t po s s th p od t on of blood c ll n th mbryo

The l re es a small a ount of its blood s pply di ectly f om the he rt th ough th hepatic rtery but the l rg r part i rec ved f om the wall f the gut th o gh th portal e n Th brings w th t p od t of digest nd oth r sub tances ab- bed thr ugh th intest nal mucos The portal n nd hepatic rtery ent th l r togethe nd both b n h pe t dly Th b a h tra el sid l y d w th ne o m e h n hes f th b l duct and a lymph v sel n the p rtal c al Thes c t ed a e d of c nn t ti k wn as Gl n cap le In pla e f ap ll ri th e are m what la ge es el the nu d with phago- cyt c o K pff cells in th i wall The inuso ds f all jo n t f m th hep t ei s th t drain the l nt the inf e a ca Th li er ll e rr ged n e d pl tes n rm ated b th



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Metamorphism At temperatures and pre ures higher than tho e normally encountered in dia gene i important changes take place in the min eralogy and texture of mo t edimentary rock The e change are termed metamorphi m and lead to the formation of metamorphic rocks It is obvi ous that there is no harply defined boundary be tween diagenetic and metamorphic proce e *See* METAMORPHISM

Metamorphism may either be local in nature as in the vicinity of a l ody of intru ive igneou rock or it may be regional occa ioned l y a ri e in tem perature pre sure or both over a con iderable area Reactions in both contact and regional metamor phism are determined l y the prevailing pre ure and temperature by the compositi n of the rock units and by the kinetics of the po sible reacti n Understanding of these reactions has l een increas ing e pecially since the introduction of water as a component in sy tems studied in the lal oratory and the investigation of material tran port during metamorphism Metamorphic reaction are appar ently nearly i ochemical although the tran port of certain elements suggests that mall volume of rock undergoing metamorphi m cann t afely l e regarded as closed systems *See* SILICATE PHASE EQUILIBRIA

Melting and crystallization At till higher tem peratures melting of rock units l egin The c m position of rock melts depends on the composition of the parent material on the ratio of liquid volume to that of the olid residuum on the temperature and pre sure during melting and on the degree of equilibrium attained l etween the liquid and s lid pha es The liquid fracti n may m ve into higher levels of the earth s crust and may even l reak through to the surface a lava or other volcanic products At the lower temperature higher in the crust crystallization n rmally take place the na ture of the re ulting solids i determined largely by the initial composition of the liquid and l y th conditions pre ailing during cooling With the ai l of pertinent lal oratory studie the relati n hip between many different igne us r ck type from th highly silicic granites through the interme liate gabl ros to the ultramafic perid tite and d inites have l een sati factorily e tal li hed alth ugh the major que tion of the origin of the l ulk of the ili ceous rocks of the upper cru t i still larg ly un answered *See* MAGMA

This que tion lead dire tly to th que ti n of the nature and extent of exchange l etween mantl and cru tal material and t th e ex hange l m t rial between the c re and the mantle H w er a long as knowledge of temperatur in th mantle and core and of the beha i r and m ement f material in the mantle i a circum cril ed n is at present th e di cu i n f th es pr be low the l a e f the cru t i n t very fruitful

[illegible]

Bibliography W Fit l Stru tural C nt t in C ystallin Systems and Th i Imp rt f Ge logical Problems Geol Soc Am Sp l per

th body and th l er is ne of the new es els arise in mese chym w thout any c n ection with l ady establ hed es el T th s th re are two repl es (1) th sem t c qu t on of a defin tion f m sen hyme and (2) th bs rvati n th t hat seen the r gin of a blood ve sel in the apne ra e f the l men ot the o ig n of the cell Bec use the ll of the me nchyme come from various ou ces a d e entually develop al ng spe- c lines, th po th l ty th t they po es d ffe ent potencies annot b ruled ut It s therefo e possible that end thel m of the blo d ssels ti ue specifi f m the t et

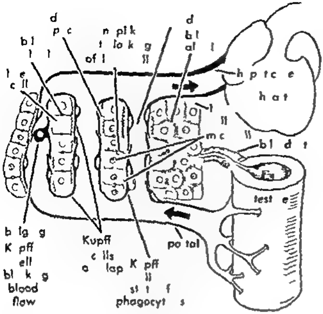
Role of mes d rm The co ept of the me n chym bec m s st ll m imp rtant when the c n tributi n of th mesoderm to the development of th h r is cons d ed The n an be little doubt th t some e tebrate f rms th splanchn mesod rm mesothel um i the ic nity of the li er l ge prolif te a d co tr b tes ells that comb with the e dod rm l anlage t p oduce th liver ma Th prob b l ty is great th t thes cells becom ular t ssu and hematopoiet c ti e. It h uld be emph zed that the contribu l th mesoderm is most e sp ou n f rms th t h e little r y lk sac I the chick and the lizard, both of hi h h large y lk sac no uch co trib t n i m de The bl od isl nd which re th a l g of the ascular end thel m nd hema t po et ti e acc d ng t the ngi bla t n cept, arise in the pl h m sod rm of the y lk , and e c n p ly re t ted to thi a m th h k It ha been assumed th t the hem to p et ti e d lopin at first in the bl od is- la d seeded int the l er f om ther and lat r the pleen and b marr w they de vel p Th e i c n d bl e d ce that such seeding occur especially f om th blood types f freemartin twi n c ttle d i mammal nto h h bo m rr w h been inject d foll wi g x ra irrad t n In both c se the f ign ed blood c ll typ c ti s t be p od ed indefi n ly di ati g th t s cce sful t a plantati [hem topo et c t ss ha oc ed

I those verteb tes i whi h the yolk c i s- tu l, blood i l nds do app en the tuge, b t th ghbor g plan hn m od rm makes cont but n t the l n The pl hn mes d m at the l r or te tin l p rtal wher the li er anl g rises, i d e tly o t u by way f the yolk t lk w th th e f the y lk ac, whe e th bl d l nd lly a i S em gly the wh the y lk sa i ed ced the pot nt l ty f f rmi g n bl st xt nded to the a t r r i t t l port l n The ell nt buted by the spl n h n mesod rm r by m en hyme" d d f m it devel p nt h m top t c t s e cell c co d g t some i vestig t r It s not w thy t at non f th m chym e m t devel p int con ect t u Th c necti e t f th l ma th th b hi g p rt l i d h p t ary

Structural development The de elopm nt f the cytoarchitect re f th li er and f the bile d ainage sy tem ha been tudied thoroughly in mammal The anlag of th li er i ordina ly sa d to d el p nt a ma of anast mosi g co ds with the nu o ds f rming a network in the spaces The process of formati n was considered to c n st f a pen tration of a larg r em by the c ds in s ich a way that they become completely surro nded by nd thelium Th educes th former cyli dri al e il to a network Th s p ocess was named inter c escence by F T Lew s The concept of the li er cord has bee challenged with , onside abl justifi cati n by H El a si ce the adult the paren hymal cell cur in plat s rather than n cord of pair of cell as is freq ently d agr mm d How ever n the chick at l ast a tudy of the early de elopme t of the pa enchyma h s l d t the con lu n that the bas f rm i deed th cord with the pl tes pr d ced by widen f the cords to form wh t has been de gnated muralium by J K ng bury rather than a netw rk In a y case there are at first neither bile cap lla e n a bile drai ge ystem The part f th di rtic lum that is t fo m the b le d ct nds bruptly at the l er mass and ts ws of cells are continu us with the ord f th p renchym The li r h been likened t th glands f the dig ti t act with the l e ords eq lent t th al eolu and the bile c pill ries to their lum s The p ttern of de lopm nt howe er q te d ff rent for the d ct does n t b nch ep tedly with a presumpt e al olu at th end f each b anch b t rath the o d th mselv b nch f eely d n t m e to f rm a three d me s onal netw k i which no em e f the l e l r st u tu e can be d o er d There at this stage n i dic t n f l b lar st uc tu unle s th wh le m s is con dered a s gle lobule w th bl d enteri g thr ugh a ein at o e end pa g th gh a scul network and l g by ei at the the

Growth As the m s g w t engulfs the p t l ein o i n w f eq e tly id the portal ve p trates the m s alo g with a sh ath f c nn c ti e t ssue The p rt of the d erticulum th t will l t bec me the b le du t r t at with the stump of the p rt l ein d does n t p trat th gr w i g mas lth gh t r tains ts tinuity with the li ords The b hes of the bile d ct that company the b an h of the p rtal ein with n the l er ma re de d f m the co d of ll d j t t the ein d n e ti e tis The b le p lla ha e ari n ppar ntly b n ng spo- d cally d ffe nt pl s t ra d m n the a s t mo ng netw k f p e hymal ll cords to f rm two k th t ti ally e pa d unt l they h m co fl t, prod ng a gle c t o n tw k.

D t f rmation In th e c ds next t th pe e t t g port l e n nd n ect e ti e th ell e t to the t e ti b c me fl tt ed d the lum w den t p duce th p ct l g go d l ed a the c al f Hering The de of this



F g 1 Schemat c d agram of the l ver as a mass of cells (st ppled) based on elect on m croscopic observa t ons

work of sinusoids The whole parenchyma is di vided into architectural units the lobules A lobule is a thimble shaped mass of cells hexagonal in cross section and drained by a central vein which is a radical of the hepatic vein Five or six portal canals course along the periphery of the lobule Between the cells of the hepatic cords or plates are minute ducts the bile canaliculi that form a continuous network throughout the lobule and at the portal canals drain into the bile ducts carrying the bile ecreted by the cells to the intestine

EMBRYOLOGY

General theory According to conventional ac count the liver arises as a diverticulum from the floor of the foregut This soon l ranches into two the anterior branch destined to form the liver parenchyma and the po terior the cystic duct and gallbladder Of particular importance is the re lationship of the growing liver mass with the large veins that course along it from the yolk sac allan tois and the posterior part of the body As the liver grows and meets the e ve els the ves els are pene trated and broken down into a network of small ve els in the spongework of parenchyma Through out the eml ryonic and fetal period as long as the yolk sac or allantoic circulation per ist channels carry the major part of the blood through the liver ma s but with the ces ation of the e extraeml ry onic contril utions the e channel cl e and the portal vein the sinu oid and the hepatic vein of the adult form remain (*see* EXTRAEMBRYONIC MEM BRANES) The history of the ves els and their re lation to the liver varies greatly in different vertebrates and it explain the variation of venous patterns in adults from form to form as well as the many anomalies found

The actual form of the liver in the vari us erte brates and in individual species implie that it is extremely pla tic It has been described as a pace filling ma s that accommodate it elf to the pace available This concept is to a certain extent sup ported by the changes in hape that may occur as a growing tumor competes for space or as the hape of the space is changed by tight lacing of a cor et It seems clear that at least from the point of view of function the history of the ve els and the hape of the liver as a whole is quite irrelevant A long as the basic pattern of portal vein sinu oid and hepatic vein persists the liver functions normally

Classical theory From the point of view of the clas ical germ layer theory the liver has three sources of ti sue (1) the parenchyma is entoder mal arising from the floor of the foregut (2) the sinusoid linings and the hematopoietic cell if present are from the angioblast (3) connective tissue particularly in the portal canal is from the mesenchyme The surface for the mo t part is covered by the mesothelium of the peritoneal lin ing In recent years almost every aspect of this point of view has been challenged It has been a erted that new endothelial lining of the inu oids and possibly the hematopoietic cells ari e in situ from me enchyme incorporated in the growing liver mass and are thus independent in origin from existing vessels or from the blood i land and hence independent of anything corre ponding to the an giobla t It has al o been a serted on the l a is of an extensive review of serially sectioned embryos of a large number of species of all cla es of verte brates that a sub tantial part of the parenchyma itself may be formed from me enchyme derived from thickenings of the planchnic me derm much as the adrenal cortex and part of the meta nephros are formed The description of cell ori gins from static stained ections may lead to a confu ed and chaotic picture when explanation i difficult and uncertain On the other hand the study of cell origins by experimental techniques has proven difficult

The cell origins of various structures derived from the ectoderm has been extensively studied in the amphil ian and avian egg and the role of inter relations of tissue in induction beautifully demon strated experimentally Nothing like thi seems to have l een demon trated for structure derived from the entoderm It seems that in l oth amphil ian and the chick the e tructures are self differentiating from very early stage perhap existing as part of the l a ic pattern of the egg *See* FATE MAPS EM BRYONIC

Role of mesenchyme The que tion of the c n tril ution of the me enchyme t the va cular pattern and even to the parenchymal ma i of a different s rt The angi l la t concep t would derive all en lo thelium from the original l lood i lands by a proc es of progre ive sprouting It validity ha been repeatedly and emphatically challenged There e m little d ul t that after the pattern of l lood and lymph ve els i def nitely e tal li l l n w e el d ari e by spr uting from ol l one H w ever it is definitely a rted that in many part f

the bod nd the li er is one of the new ves els m arise in mesen hyme w thout any connect on with alread establ hed e els To this there are two repl es (1) the semantic qu ti n f defin tion of mese chyme and (2) the observat on that what is seen i the o igi of a blo d es l is the appearan e of th lumen not the or g n of the ell Beca se th c lls f the mes chyme me from various sou ces and ventually d elop along spe- f lines, the pos bility th t th y p s e d fferent poten es c nnot b ruled t It the ef e pos- sible that end thel m of the blood e els ti sue pec fi f m th ut et

R le f m s de m Th concept f the mese chyme becomes till m e imp rta t when the con trib u n f the me oderm t the de elopment of th l e dered There can be little doubt that, in some tebrate f rms the planchn mesoderm or mesothel m in th ic ity f the liver anlage pr lif rates and ont ib utes ells that combine with the dod rmal lage to pr duc the liver m s. The prob b lity s great th t the e y become va c lar t ssue a d hematop ieti It ho ld be mph ized that the contribu tion f the mesod rm is most n p cuou n forms that ha littl or no y lk s c I the ch ck a d th lizard, bo h of h h l rg y lk sa no s ch co trib t n m de The blood i l nd wh h ar the a l g f th scular endothel um nd hema t po ei t ue ccording t th a giobl t con cept, arise i th pla ch ic mes d rm f the yolk sac and re c pt u ly restr cted to th area n the chick It has been a s med that the h mato- poieti t e d l ping t fi st in the blood s- la ds, seeded int th li er from th re and later to the *pleen a d bone marrow a they de vel p* Th r n d ble ev de e that h seeding occ espec lly from th bl d type f bree ri tw ns in c ttle a d m mmals into h b bon m rrow has be jected foll wi g x a ar d at o In both es the fo e gn ed blood ell type co t t be produced i d fi an ly d c t ng th t a f l tran plantat in f them t po tic t s e h s oc rred

I those ert b at i wh h the yolk ac is t p l blood lands d ppe on the e tige b t th ghboring spl n ic mesoderm mak s contr b t t the l r The pla chnic mes d rm at th anteri i t n l p rt l whe e the l n anl ge ar ses, s di e tly c ntin ous by way f th lk s lk th th t of th y lk a wh th bl od l d u ally ari Seemi gly the wh n th y lk s ted ced the pot t l ty f f rm g s g bl t is e t ded to the anteri r testi l portal e g on. The ll ntr b ted by the pl n h c mesod rm by mese chyme de ed f m t ma des l p i to h mat p t t ll a co d g t some est g tors It tew rthy th t n f th mes chym se ms t dev l p t con ectiv t ss e The c n ect e t se f the l e arises f m mesen hym th t l t r n ade th l m th th bran h ng p rt l e n nd hepatic artery

Structural development *Th e de elopment* of the ytoarchitecture of th li r a d of the bile drai age sy tem h s been tud ed th oughly in mamm l The anlage of th l r is ord arily s d to devel p i to a m s of ana t mosing cord with th inu oid fo min a netw rk in the space The process of f rm tion was considered to c ns t of a pe etr tion of a larger ein by the co ds in h a way that they become ompletely urrounded by endoth lium This red ces the f rm r cylind cal vessel to a network Th process was named inter cres ence by F T Lewi Th concept of the l er cord has been challenged with conside able just fi catı n by H Elia si e in the adult the paren chymal cell ccu in plat s rather than in cords of pairs of ells a is f equently diag mmed H w e er n the chick at l ast a st dy f the early de- el pment of the pa nchyma has led to the c n clu n that the b ic fo m is nde d the c rd w th the pl tes p duc d by wid ning f the co d to form what has been designated a muralium by J Kingsbury rather than a netw rk. I any ase there a e at first n ther bile c p lla i nor bile drain ge sy tem The part f the di erticul m that is t form the b le d t end abruptly at the li er mas nd it rows f cell a ontinuo s with the co d of the parenchyma The li has been likened to oth r gla ds of the dig ti e tra t with the l er c ds equ ale t to th al eolu nd the bil cap lla es to th r l m ns Th patte n of devel pment is howeve quite d ffe ent f the d t d e not branch peatedly with a p es mpti e al l s at the end f each branch b t rather the ords them el br h freely a d ana t m e to form a th ee-dimens nal n tw rk i wh ch em *bl n e of th alveol structu e can be disco e ed* Th e is t this st ge no ind ation of lobul struc tu e u less the whol mass s c d d a gle l bule w th blood ente g through a ein at one end p s ng tl gh a v ul r etwork a d lea g by a in at the other

G uth A the m s gr ws t engulfs the port l e n or as n w f equently d th p t l ei pen t ate the m s l ng w th a he th of connec t e t s *The p rt of the d erticul m th t will* lat be m the b l duct ret eat w th th *stump* f the p t l ein nd does n t pe t te th gr w ng ma although it reta its co tin ty *with the* l co ds The branches f the b l duct that ac omp y th branches of the portal v n with the l e m e deri ed fr m the ds of cell ad jace t t th ein and conne t ve ti ue Th b le cap ll s h e arı en app tly beginn ng spo- ad lly *in d fferent places at random* i the s- t m i g network of pare *chym l ell* o d t f rm netwo ks th t continually p nd unt l they become c fl e t, pr ducing s ngl c nt uo netw rk

D ct fo mation In th ord n xt t th pe e tr t g p rtal a d c necti e tis u th cells ne t to th c t e t s becom flattened a d th lum n w d to p oduc the p tur l g des ibed as the n l I He g The s de f th

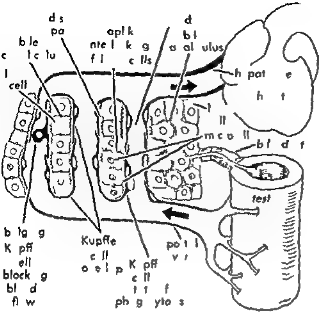


Fig 1 Schematic diagram of the liver as a mass of cells (stippled) based on electron microscopic observations

work of sinusoids The whole parenchyma is divided into architectural units the lobules A lobule is a thimble shaped mass of cells hexagonal in cross section and drained by a central vein which is a radical of the hepatic vein Five or six portal canals course along the periphery of the lobule Between the cells of the hepatic cords or plates are minute ducts the bile canaliculi that form a continuous network throughout the lobule and at the portal canals drain into the bile ducts carrying the bile secreted by the cells to the intestine

EMBRYOLOGY

General theory According to conventional account the liver arises as a diverticulum from the floor of the foregut This soon branches into two the anterior branch destined to form the liver parenchyma and the posterior the cystic duct and gallbladder Of particular importance is the relationship of the growing liver mass with the large veins that course along it from the yolk sac allantois and the posterior part of the body As the liver grows and meets the vessels the vessels are penetrated and broken down into a network of small vessels in the spongework of parenchyma Throughout the embryonic and fetal period as long as the yolk sac or allantoic circulation persists channels carry the major part of the blood through the liver mass but with the cessation of the extraembryonic contributions these channels close and the portal vein the sinusoid and the hepatic vein of the adult form remain (*see* EXTRAEMBRYONIC MEMBRANES) The history of the vessels and their relation to the liver varies greatly in different vertebrates and it explains the variation of venous patterns in adults from form to form as well as the many anomalies found

The actual form of the liver in the various vertebrates and in individual species implies that it is extremely plastic It has been described as a space filling mass that accommodates itself to the space available This concept is to a certain extent supported by the changes in shape that may occur as a growing tumor competes for space or as the shape of the space is changed by tight lacing of a corset It seems clear that at least from the point of view of function the history of the vessels and the shape of the liver as a whole is quite irrelevant As long as the basic pattern of portal vein sinusoid and hepatic vein persists the liver functions normally

Classical theory From the point of view of the classical "germ layer theory the liver has three sources of tissue (1) the parenchyma is entodermal arising from the floor of the foregut (2) the sinusoid linings and the hematopoietic cells if present are from the angioblast (3) connective tissue particularly in the portal canals is from the mesenchyme The surface for the most part is covered by the mesothelium of the peritoneal lining In recent years almost every aspect of this point of view has been challenged It has been asserted that new endothelial lining of the sinusoids and possibly the hematopoietic cells arise in situ from mesenchyme incorporated in the growing liver mass and are thus independent in origin from existing vessels or from the blood island and hence independent of anything corresponding to the angioblast It has also been asserted on the basis of an extensive review of serially sectioned embryos of a large number of species of all classes of vertebrates that a substantial part of the parenchyma itself may be formed from mesenchyme derived from thickenings of the splanchnic mesoderm much as the adrenal cortex and part of the metanephros are formed The description of cell origins from static stained sections may lead to a confused and chaotic picture when explanation is difficult and uncertain On the other hand the study of cell origins by experimental techniques has proven difficult

The cell origins of various structures derived from the ectoderm has been extensively studied in the amphibian and avian egg and the role of interrelations of tissues in induction beautifully demonstrated experimentally Nothing like this seems to have been demonstrated for structures derived from the entoderm It seems that in both amphibians and the chick these structures are self differentiating from very early stages perhaps existing as part of the basic pattern of the egg See FATE MAPS EMBRYONIC

Role of mesenchyme The question of the contribution of the mesenchyme to the vascular pattern and even to the parenchymal mass is of a different sort The angioblast concept would derive all endothelium from the original blood islands by a process of progressive sprouting Its validity has been repeatedly and emphatically challenged There seems little doubt that after the pattern of blood and lymph vessels is definitely established new vessels do arise by sprouting from old ones However it is definitely asserted that in many parts of

bod and the live is one f the e new ve sel r anse i m se hyme w thout a y n ectı n h already establi hed e sel To this there are replies (1) the ema tic que tı n of a defi ı n of mese chym and (2) the ob ervatı n that at is see ı th o ıgin of a blood ve el is the pαran e f th lumen not the or gın f the cells se the c ll of the me nchyme ome f om u ces a d ev ntu lly de elop along pe- lines, the p bility th t they p s ess differe t tencies c n ot be led t It ıs the efor po l th t end th l um of the blood es ls ı tı ue f om the o t t

Role f mes de m The conc pt of the m sen m becomes till mo e imp tant when the con but of the mesoderm t the dev l pme t of h r n ıdered There c n b little do bt t, in some rtebrate f rms the splanchnic od rm, or mesothel m n the vic n ty of th er anl ge pr lif tes and e trib t s cell th t commune with the dodermal anlage to prod ce the er m s. The probab lity ıs great that these cell become a lar ıı and hem t po t It hould be emph zed that the contribu t f the me d rm mo t consp u us in forms th tha Little y lk I the ch ck and the Lizard, both f h h e l rge y lk acs n ch contrib t n ı made The bl d ı lands which e th a lag f th a l nd th h m and hema t iet e cc rd g to the angı blast c n ent, an e s th pla chnı mes derm of the yolk sa d r c usly t ct d t th s a in th chi k It h bee a umed th t the hemato- po e tic de lop g t first ı the bl od is- lands, eeded ınt the l e f m there nd lat t the spleen a d b m w they de- vel p Th r is o derable e ide ce th t uch seeding occ espec lly f m the blood typ of from ru tw in ttl nd in mammals into h h bo e m rr w ha bee ı jected f ll wing a n. In both cases th f g red blood ll type cont ues to be p d ced ı d fi a l ı d at g that a er f l t anspl tat them ı poı t c tissue h occ rr d

I those teb ates in wh h th yolk s c es- blood la d do ppe r the estig b t th ghboring pl n h ı m d rm m kes contribut n t th l er Th splan hn c m d rm th ant r test nal portal wh e th l l ge a ses, is d ectly ont nuou by way f the lk talk w th that f the yolk c wh the blo d ı d u lly ar e Seemı gly the wh n th yolk sa ed ed th p te t lity of form g bl t t xtended t th ant r ı t stı al portal r g n Th cells nt b ted by the pl nch nic mesod rm o by mes hyme de ed f m t may dev l p ı t h m top etic t ue ell a cod g t som ı gat r It ı n teworthy that f th m ench me em t d l p ı t t u Th nects t of th l er mes f m mese chyme th t l te ad th l r mass w th th b a h g p rt l e d h p t c ery

Structural development The devel pment of the cytoa hit ture f the li r nd of the bile drain ge system has been tud ed th roughly in mammals Th anlage f the li r is ordinarily s id t de elop ınt a ma s f a ast mosing ords w th the s usoıd f rm a network ı the space The proc ss of formatı n w s consid red to c sı t of penetratı n of a l rge eın by th c rds n such a way that they become complet ly s rrounded by end thel um This reduces the f rmer cylindrical ve l to a netwo k This p oces was named inter c escen e by F T Lewis The concept of the l er co d has b en challenged with co side able ju t fi c tion by H Elias nce in the adult the par n hym l cell occ r in plates r ther than in cor l of p rs of cells as ı frequently diag ammed H w eve in the ch ck at least a st dy of the arly de v l pme t of the pare ch ma has led *to the con* lu ion that the ba ic f rm ı ı deed the ord w th the plates produ ed by widening of the cords t form what has been designated mu alium by J King bury rathe than a network In any c se there are at first neithe bile p llarıe *nor a bile* d age y tem The part f th dı erticul m that t f m th bile d t ends ab ı tly at the li er ma s and t row of c lls are tinu with the c d of the pare hyma The li l as been l kened to ther gl nds of the d ge t e tract with th li e rds equi alent to th alveolus nd th b le c p ll s t the r lum ns Th pattern of d l pment is h weve q ıte different lo the duct d es not branch peatedly with a p *umptı e* al lus t the e d f each branch b t ather th ords thems l es b n h fre ly d ana tom e to form a th e-dimen nal n tw rk in wh h n m bl ce of th al l tructu e ca be d sco ered There is t this stag no ı d tı n of lobular st uc t e nles the wh l mass is cons de ed a le lobule w th blood e te ı g thr ugh a eın at on d p s th ugh a ascul r netw rk a d l ng by a n at the th r

Growth A the ma gr w ıt engulf the p t l r as ı w frequently d th portal pen t te the m l ng with a sheath of c nec t e tissu The p rt f the d vert c l m th t will l ter bec m the b l duct r t ts *with the* st mp of the p t l ein a d doe t penetrat *the grow* ı g mas ltho gh ıt etaı s ts continuity with th l r co d *The bran hes of the b l duct that* c mpany th bran he of the p rtal n with n th l er m e de ı ed fr m th c ds of ells ad j ent t th n and c n ect e t s The b l apillar h arı app e tly *beginning* spo- adic lly *d ffere t places* t nd m n the na mo ng twork f pare hym l ll cord to f rm n tw rk that ontı u lly expa d u t l they bec me nfluent, ı od cı g sı gl c tı u u two k

D t f mat n In th e c rd *next to the* p n t g p rt l a d nnect e tı the c lls *n xt to the connectı* t ue be ome fl tt ned d the lum n wid ns to produ the p ct e long go des bed th n l of H g The s d of this

canal next to the portal vein is of thin pavement like cells and the opposite side is of cuboidal parenchymal cells with the bile capillaries between them emptying into the widened lumen As the connective tissue develops it surrounds the cord completely and the latter become completely transformed into a thin walled tube similar to the cholangiole of the adult liver Cholangioles thus developed form a continuous network surrounding the portal vein Only later do more conspicuous channels appear in the network with walls thickened to form the bile duct Although the latter *appear to run parallel to the branches of the vein* they actually still form a much elongated and attenuated cylindrical network Only at the end where the finer branches follow the terminal branches of the portal vein into the liver mass do they continue to receive bile capillaries The remainder of the original thin walled network diminishes as the definitive ducts appear and finally seems to disappear entirely for the cells that formed it cannot be identified in the portal canals *Finally* with the completion of the portal canal the network of parenchymal cell cords adjacent to it widens and fuses to form a continuous limiting plate *Where the anlage of the extrahepatic duct* comes in contact with the new duct formed in the liver mass the lumens become continuous thus establishing the definitive bile drainage system The process of duct formation within the liver mass continues as long as the liver continues to grow by the development of new lobules In the rat which has no gallbladder a more extensive part of the primitive thin walled network becomes converted into ducts than in the mouse which has a gall *bladder It is to be emphasized that in the original description of the canal of Hering the subject was* an infant One seeks in vain to find such a structure in the normal adult liver where the bile capillaries empty directly into short thin walled cholangioles which in turn drain into the terminal branches of the bile ducts

Growth The growth of the liver by the increase in the number of lobules is a process of intussusception The growth occurs throughout the liver mass *and not by addition to the surface As the mass of* the liver increases so does that of the individual lobule As the lobule increases the portal vein branches and the amount of parenchyma remains constant with respect to the amount of vein With the production of new canals of Hering and finally of ducts the connective tissue and portal vein penetrate the liver mass as before Corresponding to this new channels appear in the sinusoidal network opposite the portal canal which are continuous *with the hepatic vein to form* the central veins of the new lobules The lobules of the liver are remarkably constant in size throughout and remain constant as the liver grows The terminal branches of the portal veins are equidistant from the central veins throughout This relationship is considered to be developed and maintained by hemodynamic action according to a theory developed by K Thoma and applied to the liver by F P Mall

Thus in the development of the cytoarchitecture of the liver the bile capillaries seem to arise autonomously in the liver cords the bile ducts by an inductive action of the portal connective tissue and the lobular pattern by hemodynamic action as the mass increases [J W WI]

ANATOMY

Human anatomy Both function and structure of the liver can be understood only if one knows how *this organ is associated with the blood stream and* the intestine Both histologically and anatomically the human liver is one of the simplest of vertebrate livers and is u ed here as a model for the vertebrate liver

Blood supply The blood which streams through the spleen and through the capillary bed of the stomach and intestine is collected by veins which converge into a wide but short vessel known as the portal vein This vessel enters the liver through the porta hepatis or the door of the liver whence

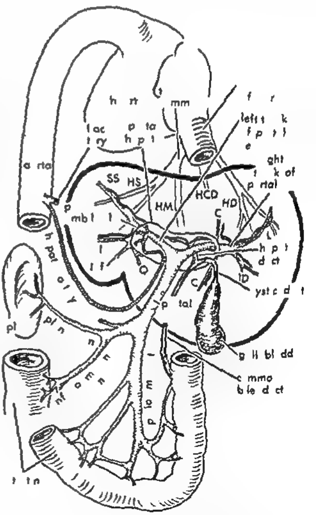


Fig 2 Schematic diagram of human liver and its major dorsal connections R m e a rtae C central I intermediate ID inferior dexter Inf inferior sinister L lateral Q quadrate SS superior sinister V venae hepaticae HCD dorsocaudal HD dextra HM media HS sinister

th sam portal n This do r of the li e a broad dep es m th infe r po t r or d r o ra dal rfa e of th org

Th port l ei a portae comm branches the porta h p t i t a hort ht trunk the tra ca. d ter d i to a l g left trunk the tra cus te From th ari e two t u ks branches or ram h ch p etrate deep r the bst f the l r a d bra ch e te ly The e intrahepat port l n branches f m th ores ftun l alled p rt l c l

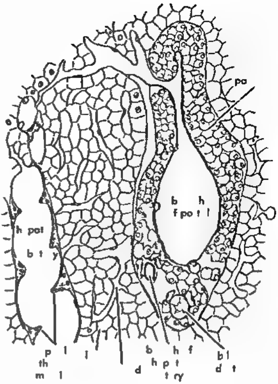
Th h uppl ed w th e bl d which is rich ur hm t by mea s of the portal vein Th eno blood of the p tal n is uppl ated b arter l blood wh h i b ght t the liver b th hep t artery elat ely thin essel h h es f om th celiac arte y d by n oc l es ory hepat tery The hep t ar tery enter th li e th ough the p t hepatis Its b h r n l de th e of th po t l em within th portal al Oft there are tw more hep t art ry b an hes i p tal canal These ll a t ri ar con cted w th an other b t m Th b an h f the p rt l and f the h p t c artery mpty i t th ee d l net rk of spe lized pillarie th so lled l er d Th i d i t di h g th blood i t trib t ie f the h p tic h h c u e w thi the called hepat l The l t hepat e ns mpty t the fe o

C als t ms The po t l nd hepat can l r t m of t n el e t ly dep dent f ach ther The p rpe d c l rly nd epa r d b i t rv g l e pa en hyma a d s d

Th ind d l b ches f the p rtal nal h t n th po t l a d h pat rterie r n t m ith th e ghb that h bra ch f the e es ls h ts wn h rply de ted terr t ry h h it pple Th d n f g t rr to es of nd d l h pat c e nt ib t es eq lly h rp S g o m t be wa f th l k f t e n t e the a t m s l t al If ne b a ch of th e essel is lig ed, its a t e t r t rv f pply o d a ge d generates Y t, becau e f the perp d l d eta ls g f port l a d hep t c l th hum n liver u fied It s u t r pt d n twork of s nds, th p e b t ee whi h a e filled w th l

Bl d t A y tem f bile d t r fr m t ble p lla e a l c l betw n the l er ll Th bl d t r is n the port l al but they d t th i nte t i a d r t op- po t th i f th blood fl w I th med m ed d th l portal al tw m r bl d ts d d th gle b h f th p rtal e Th d t a t e w th the ghb s i th port l ca l

The l l d t f m all th port l ca l co rg u f rm th hepat d ct r d tu hep t us m th port h pat Th d t h s l g o t



Fg 3 t f th p

pouch g the gallbl dde ca f ll wh ch h s hap m lar t th t of el ted p Its t lk d t y ticu the y ti d t Bey d the j ction f the h p ti d y t duct the d t y tem co t de the n me f th e mm n bile d t or d ctus h led ch nd fi lly empt e t th duode um r pp p t n f th m ll i t t n S GALLBLADDER

Comparative anatomy I e tebr t ther s o k wn org which i btlv be lled a l er O the the h d ll ert b te po l r ll p th p be a of t l m ge o mple t uct th t th l e h n t e lly hape f t w It a pl t c m that fills o t p n m ng the th org i th abdom l c vity T w d the b dy w ll the l e co ex Wh t i t ct w th th o gan th e g m k im p s

L ho d t Th stom h ep thel m f the A d a p flat o tpo ket g wh h p je t t th b d ity Bec u e th blood p- ply a d d i g of the lamell e n t u de t d t s imp sibl t est bl h wh th the e d ble h et f cell may b h mol g to l er ll pl te

I *Amph ox* the st bl nd tp cket g f th f r g t wh ch id ed by m ny t be h m l of the l

F t b at I the gr p P c th fi he the l f b th C l tom ta d Myx f rm s c s t f a cra l a d ca d l l b n e ted b n thm I th mm n tes l rva f l mp eys P t m o t f me the l n i t f two l g l ft d ght l b wh ch r e t d b a thi

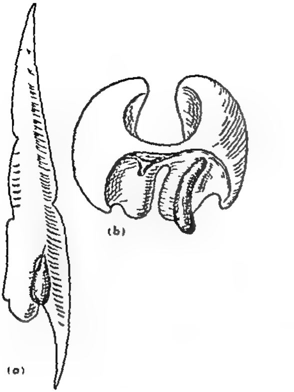


Fig 4 (a) Dorsal aspect of l er of Amph sbaena dar w n a l zard (Rev museo argent no c e c nat 3 165 1957) (b) Liver of All gator m ss ssipiens s

helf During metamorphosis the liver lo e its duct system and shrinks to form a ringlike mass behind the pharynx Among the Selachii the liver is hor eshoe haped and the free ends point caudad It has a very high fat content The shape of the liver in the Teleo tei undergoe many variations In many teleost and ganoid specie the pancreas is located within the portal canals

The liver of the caecilians Apoda is divided into numerous lobes which cover each other in a shin gl like fashion They are all connected by a narrow longitudinal bridge The liver of salamanders and newts Caudata is lobated in ome species and uni fi d in others The liver of the frogs and toads Salientia consists of two large lateral lobes con nected by a broad median portion The liver of the amphibians receives venous blood not only through the portal vein but also from the lower extremi ties through the abdominal vein

The unified liver of snake Serpentes and liz ards Sauria is adapted to the shape of the body The liver of turtle Chelonia and crocodiles Crocodilia consists of a right and a left portion connected by a narrow isthmus

The liver of birds is a rather unified bilobed organ

Among the mammals with unified livers are the Ruminantia the Cetacea and ome Hominoidea such as man the orangutan chimpanzee and gib bon but the gorilla has a lobated liver The livers of all other mammals the anatomy of which has been recorded are lobated

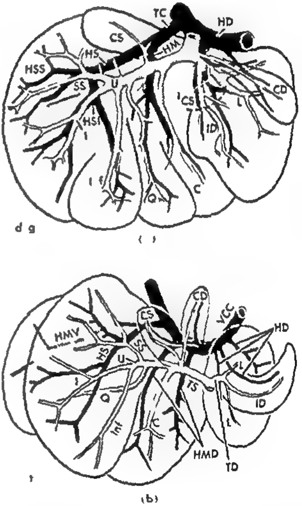
In unified livers the hepatic veins run at almost right angles to the portal canals but in lobated livers with deep incisions between lobe the large hepatic veins run parallel to the large portal ca nals and crossing occurs only among the smaller ves els In lobated livers partial hepatectomy is easy but surgery on unified livers is very difficult

Among mammals there is a remarkable uniform ity in the pattern of branching of the portal and hepatic canals In spite of differences in external lobation the only basic variation in the vascular pattern is the location of th bifurcation of the common portal vein relative to the origin of the ramus centralis

HISTOLOGY

The structure of this organ of multiple function is remarkably uniform throughout the phylum of the vertebrates

General morphology The liver of all vertebrates, with the exception of adult Petromyzonidae is a



Fg 5 (a) Do s l aspect of l ve of dog (b) L ver of at Ram ve ae portae C ı t al s I inte med us ID infer o de ter Inf infe io s te L late al s Q quad atus SS s pe r s n st V ae hep t c e HD d xt a HM med a HMV v nt al di on of me- HD d xt a HMD do sal d s a of med a HS ist r HSI s n t ae rad Inf o HSS t ae rad s pe s n t ae rad Inf o HSS t ae rad s pe Ramuli CD caudatu d ter CS caud t ni te TC t un us commun T u enae port e TD de ter TS s ni t U pars mb l cal VCC v na ca a in f or

muralium, that is a ystem f c nected wall Th term l um implies that the l e e embl nst b ild g n ts t t re with m ny blong ften cylind c l li htly cro k d room the la unae h patis. Ne ghb g l nae a e parated from e an th r by w ll built of l ve o h patic cells. Thes wall also called l r plates o l m nae hep ti ll connected w th each othe and form a h ghly b an hed d ne er ending c b dal epithelium They a portı ns of the un nt rrupted muralium. As th ro ms in a buildi ted through doors d ghb g l nae com m.m t th each other thr gh pen gs in the liver pl tes in h w y that the lacunae hepat s together f rm s t a d u inte upted sy tem f con ected t nel the l byr nth hepat

Canal y tem Th l pervaded by two sys tem. of wid cyli drical t n l th po t l canals and th h pati canal which rve s commun cating struct within the li er Th e tw nal syste s d etail w th o ther but always remai sepa ated fr m ea h other by d st nce of at least 400 m cr ns (μ) E ch canal y t m is h ghly bra h d but there e n s connection between b a ches e of the sam l Th bra h g of a h nal sy t m r mble th t f tree.

I ost c s, the b ch g of th port l nal system app o m t s th d h tom u pattern hereas th hep t c l ystem tend t w d a mon podı l pattern

Limiti g plat E h po t l d h p tic l is lined b gle l ye f l ll th l mit g plate. The nti e rg n als lim ted t w d its surf ce, by a e t r al l mit g plat

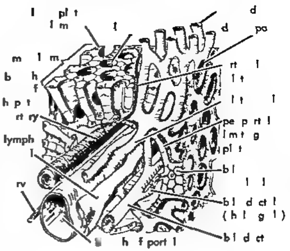
All th l mit g pl t s th e tern l the p port l h h s rr d the p rt l l d the perih p ti u r u d g th h pat c ls e u w th e ch th r a d w th the t rmal mural m Th *periportal and perihepat l m t ng* pl tes have nume ous mall ope ing th t the l mmu cate p ofu ely with the labyri th f l u e H we e neithe the canals n the la nae ar mpty t m ght appea from this de c iption A three d men l tw k of p l ed p ll s the sinusoids i u pe ded in the l byr th f l d co nect d th ugh the pe fo ations n the l m t g pl tes w th the bl d l n b th can l systems

The e t r l u und d by a fib us p ule e ed at most pla by pe itone l m so- thel m Th n t e t e of th fib ous p- l efle t d int th nte r of b th ca l system nd ries blood e l duct lymph l nd nerv d p t the org

Cellular morphology Th l t ss e com ed f tw k d f ll th h p t lls l (par n hym l) cells a d th K pff cell

Kupff ll The e ll th pe l d et ul nd thelial ll whi h l n the nus ds Alth gh cell b nd es can b dem tr t d by th l e tr t m thod in mm n d thel m this is n t p ble in th e of th l n g f th l e t sod Hen t w bel ev d th t th i u o d w ll w s of a yn yt l h a t H weve l t n m o p tud e n 1957 ev l d the d du lity f th ell They ha lloped m g s nd l p Th K pff cell r p t t l ph g cyte The n mb of Kupffe cell a ti ph g cytes d p ds n the ds f th m me t d g t M K ely E Bl h and L Warn (1948)

Th K pff ll h e the ab lity t bl k th ll d flow thr gh the u ds by bul g t th l m th l d g t It pp und r th pt l m pe th t th d fill the t l d g l f The pac betw n th r w ll d th li e ll k wn s D se pa e w th ght by m y t be n t f t f hri kage Th le tr m c o p e w k m de t ob o s that th p n d l p ar l ty is d ng l fe



Fg 7 S h m t d g m f p rt l l w th d g l t

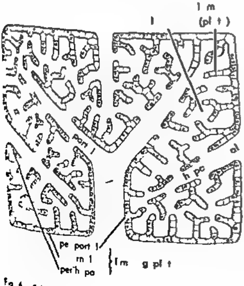


Fig. 6. Sch at diag m f th ll l truct f the liver

Liver cells or hepatic cells These are the components of the hepatic muralium The shape and volume of each hepatic cell depend on its location in the muralium A cell touching a hole in a liver plate the smallest type may have the shape of a pentahedron with an approximate volume of 10 000 μ^3 whereas the cell which is located at the junction of three laminae the largest type may have an approximate volume of 35 000 μ^3

The nucleus of the liver cell is spherical and contains a large nucleolus Some nucleoli are basophilic and others are acidophilic Small liver cells 10 000 20 000 μ have one nucleus each but larger liver cells may have two or three nuclei The liver cells contain piles of electron microscopically demonstrable double membranes the endoplasmic reticulum and spherical to rod shaped mitochondria with internal double membrane The liver cells are fastened to each other by club shaped projections of cytoplasm of one liver cell which fit into depressions of the adjacent liver cell in the manner of snaps Another mechanism of holding the liver cells together is provided by the polygonal network of bile capillaries the canaliculi Each mesh of this network surrounds a liver cell Because the walls of the bile canaliculi are tough this network gives the muralium a strong support *The walls of the bile canaliculi are condensations* of exoplasm of the hepatic cells and it appears in electron micrograms that through the walls of the bile canaliculi adjacent liver cells are continuous with each other Microvilli project into the lumen of the bile canaliculi

The facet of the liver cells in contact with lacunae is studded with short microvilli The space between these microvilli is the perisinusoidal space of Disse

Comparative histology Most lower vertebrates have laminae hepatis predominantly two cells thick the muralium duplex but the mammals and the songbird Passeriformes as well as a few lower birds have liver cell plates one cell thick the muralium simplex In Amphibia there is a mixture of muralium duplex and muralium simplex The latter is predominant in amphibian larvae

Minute vascularization The portal venous blood enters into the network of sinusoids through short side branches the inlet venules of small portal vein branches The inlet venules pierce the limiting plate

In man *the smaller branches or axial distribution veins of the portal vein which are 280 μ or* less in diameter give rise to inlet venules all along their course The larger rami or conducting veins 400 μ and thicker *do not give rise to inlet venules* The tissue surrounding them however is very well vascularized by side branches the marginal distributing veins which run parallel to the large veins or surround them spirally These give rise along their course to inlet venules

In the rat the large portal vein rami do not give rise to inlet venules and only rarely to marginal distributing veins so that the tissue surrounding large portal canals is poorly vascularized All portal vein branches in the mouse give rise to inlet venules as a result all periportal areas are well vascularized

In man the sinusoids enter the smallest tributaries of the hepatic or central veins only whereas in the rat and mouse sinusoids enter the hepatic veins of every caliber

Thus the livers of both *man and the mouse are* well supplied with portal blood and the liver of the rat possesses areas poorly supplied with portal blood On the other hand the livers of the rat and *mouse are well and evenly drained whereas the* drainage of human liver tissue must go through the narrow bottlenecks of the junctions of central veins with sublobular veins

The hepatic veins of the dog seal carp and a few other species are surrounded by spiral muscles which can contract on histamine stimulation These throttle muscles play a role in anaphylactic shock In most animals there are no such muscles

The hepatic arteries give rise to capillary networks around the bile ducts The venous blood from these periductal networks drains into portal inlet venules Other and more important terminations of the hepatic arteries pierce the limiting plate and penetrate to various depths in the liver *tissue They open into sinusoids at all levels* between the portal and hepatic canals

Lymphatics Tissue fluid flows from the spaces of Disse into a tissue space at the periphery of the portal canals From there *it must filter through the* connective tissue of the portal canals and through the endothelium of the lymph vessels which are present in great abundance in the portal canals

In the dog in addition to periportal lymph vessels there is a vast lymphatic plexus around the hepatic veins

It is obvious that these specific differences in vascularization render the application to man of experimental results obtained in animals somewhat problematic

Lobules Under normal conditions the sinusoids run radially toward the small tributaries of the hepatic vein This pattern gives the liver the appearance of lobulation The center of a hepatic lobule is occupied by a central vein the smallest hepatic vein The portal canals appear between these lobules and the smaller portal vein branches are sometimes called interlobular veins The *lobulation of the liver is however only an expression* of the portohepatic blood pressure gradient for when the blood pressure in the hepatic vein is elevated or that in the portal vein lowered as may *happen in disease such as heart failure* and tumors the lobular pattern is *reversed* When it is done experimentally by ligation the lobular reversal occurs in 2 minutes In these cases the sinusoids *radiate from the portal canals* which appear now as centers of lobules In the pig raccoon and polar bear liver cells along planes connecting neighboring portal canals begin to degenerate about a year after birth *In these planes connective*

... septa devel p hich gi e the l e f the e ... l a perma ntly l bul ted ch racte Th ... n h been inte p eted a a pur ly portal ... b l al h S e CIRRHOSIS ... LIZED TI UE (BIOCHEMISTRY)

PHYSIOLOGY

the ma y f ctio of the l e the p ... ppear t be th t of t ge d ... n of food Th co ept is ggested by ... f the devel ping l t the ... all rteb tes a d by the d ect tra ... n of the y lk t the l er wh ch oc ... amph b s

Food storage and use Y lk t ed food de- ... by th g ow g emb y ... amphib n blood l d e w th the m ... y lk cell Th blood s l nds coale c nd be ... d fin ti l er n o d a d the yolk ... between th m b m th ...

... bo t the t m the yolk s o sumed the tad ... t Hen ef th th p tal e com ... the i te t d on e t d with the l er ... d bring th ly d e t d fo d f m the ... the f rme y lk a n w all d li e ... co d r ble m nt of t s tored t b ... the g m eed it

F d t ed the l er cells h fly in the f m ... ide gly g n a d i th f rm of ... th d by th l e c lls f m ... fru t e d gal ct Th p n eat c ... l n f lt te th s pr e b t it ... n t yet u d r t d Gly gen c ... the ed by the l ell f m f tt ... d a d l t ac d The ti f ... p rt ly mp rta t d g t rv ... p od ced th gh ut th b dy ... by d t n f gl c s T a gr te te t ... d ed f m the b e kdown f h pat c ... d th infl e of th othe p n ... h rm n gl c g n

F t ed n the l e nd y the d f m ... wh n a ex e f th l tt ... p oces m y le d t f tty d g e ... hi h m y be f ll w d by ho-

The l m nt by the st ag of f od t ff ... el f gl lm st c n t t ... blood gar 100 mg/100 ml f bl d ... part l ly bl d pla m o ... prod d by the l e ell a well ... f th t of wh ch o ... A D d ... r d h fly n th

... Th l cell r t a gee b tt ... the b le a l c l Th ... mmu t th ugh m ll d ... h l g les w th d t wh h d s h rge ... mm n b l d ct m ll ... A pr l m v t g pl f ... gallbl dd Th l m p tl

l m of the gallbl dder s pr ided with a tr ated ... der n isti g of m cro ll It i s m d that the e m o ills re t m ntal i eab ptio f water f m the bile thu i c ea g the nce t a t on f the bile It has been ed that th gall bladde t ne e ary for l fe by the f t that ome nim l f r example the hor do t po ses gallbladd Al o s gi al em l f the gallbladde ch lecy tectomy t ha mful

An mpo tant comp nent f b le the bil ac ds e f med b th li e ell The re e ent l f r the ab o pt n by the i te t l ll of f t l pid d it mi A a d D for they mul ify and make them m scibl w th wat and thu cce bl t the d ge ti e act n f lip es p d ed by th p cre and by the inte t al glands It al o umed by me that the b le a ds a ti at th pan eat c l pa e

Bile pigments (b l rub n a d bili erd) ar cat b li p od cts f h mogl b n They r pr duced m nly by ph gocyte n th spl en d b n ma ow wh h h e ge t d yth cyt The li ell em e the e p gm nt f om th bl d st eam a d tr sp rt them nto the b le ca ali li The bil ls co t in ch le te l p d ed p rt by l er ell nd e bs rbed l ter b the i te t e Oth end pr du ts of met bol m d rta n b t n rtific ally i t od c d i t the blood tr m a e eted by the l e ell i t th bil

The l er ll ma f t a ema kable b l ty to tr n po t ub t n ag i t an o mot c p e su e g ade t s that th c e t at n f the ub- t c in the bil m lt pl of the n nt t o n the bl d Th s bil ty h bee att but d t the el tr m op cally d m nst bl do ble memb a s

Detox fi t Many p i o bst n e a e det fi d i th l r by d r dat d t nd c j g t Ho m e p rt c l rl h m e d tr yed b the l e a m la m n er Th s p pe bal f the h mo s ma ta ed the b d The Kupff ell ar th ht t pl y a mp ta t r le n th p ce The c lls l o m e p rt c l t m ti f m th blo d by th phag cyt ct ity S HEPATITIS LIVER DISORDERS [M H E]

Bibl aphy L B lk Go pp rt E K ll d W L b h *H db h d l gl ch d n A t m d W belt e* l 3 1937 H El Li m rph l gy *l Re* 30(3) 263–310 1955 H P ppe d F S h ff *L i St u t a d F t n* 1957

Liver disorders

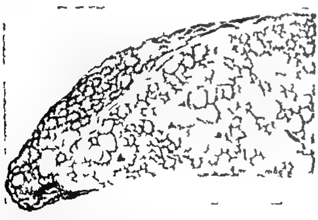
... d f th l a f p rt c l mp tan e be n f th m ny e ti l phy l g l f n t f th l g g Th l r i tim t l ned w th the met b l m f p te fat d b h d t d w th th m l de t fi t n f m y h m es d ma J m t b l w te prod t Th l ec b ut 25% of ll f th bl od p mped t f m the h art

including all of the blood draining from the intestine *See* LIVER

Cirrhosis Cirrhosis is the term applied to the end stage of scarring of the liver *It may follow re*peated minor insults or a single sudden massive injury The more common causes are nutritional deficiency as shown in the illustration (Laennec or portal cirrhosis) viral infection and injury by chemical agents (postnecrotic cirrhosis) obstruction of the drainage of bile from the liver (biliary cirrhosis) and prolonged and severe heart failure (congestive or cardiac cirrhosis) Since the use of antibiotics syphilis has become relatively uncommon as a cause of cirrhosis at least in those regions where antisyphilitic therapy is available Because the liver has a large functional reserve minor degrees of cirrhosis may have little physiological effect More severe instances of the disease however lead to early death

Malnutrition Nutritional disease of the liver is seen particularly after prolonged and excessive use of alcoholic beverages but may occur as a result of malnutrition from any cause and may even develop spontaneously in animals The dietary deficiency is not a *lack of sufficient calories* but an inadequacy of a few essential foodstuffs particularly the amino acid choline Under these conditions massive amounts of fat first accumulate in the liver cells enlarging the cells and the liver itself Such large fatty livers may have impaired function and are unduly susceptible to further injury from many toxic agents to which the liver *may be exposed Sudden unexplained death of* many liver cells may occur at this fatty stage lowering the function of the organ below the level essential for life of the individual More often the disease progresses insidiously and persistently with the development of fibrous scarring and with disorganized regeneration of liver tissue

After a period of many months or years the entire architectural pattern of the liver is distorted



Portal (Laennec s) cirrhosis of the liver The normal uniform architectural pattern has been destroyed and replaced by large and small nodules of regenerated liver tissue separated by bands and septa of connective tissue This is the edge of a large slice removed from the liver

and replaced by small and large nodules of d organized liver cells separated by bands or sep of connective tissue With this progressive fibro *and distortion there also occur significant chang* in the small blood vessels in the liver seriously a tering its blood supply The small veins draini blood from the liver become narrowed and t flow of blood *through the liver is impeded Behi* this obstruction pressure rises in the portal vei which carry the blood from the gastrointesti tract to the liver and new channels develop carry the blood around rather than through t liver Particularly important among these lat channels are veins beneath the mucosa of the esoph agus (varices) which may become eroded and b the source of massive hemorrhage In late stag of the disease the amount of blood reaching liv cells may be insufficient to maintain the bare es sential function The patient then dies in hepat failure with alterations in the blood protein a cumulation of fluid in the body cavities and th accumulation in the blood of toxic metabolic prod ucts such as ammonia *See* MALNUTRITION META BOLIC DISORDERS

Viral infections Viral hepatitis the most impor tant infectious disease of the liver may be caus by either of two closely related viruses These tw agents produce identical changes in the liver bu *differ in their mode of spread and in the laten* period between the invasion of the host and th manifestation of disease In one case the orga isms are acquired by the oral route (infected foo *or water) In the other case they are acquired b* the injection of serum from a patient with the dis ease or carrying the virus The former disease called infectious hepatitis the latter homologou serum hepatitis Jaundice is the striking clinica feature of viral hepatitis although other symptom such as malaise abdominal pain and loss of appe tite may also be distressing The effects of the viru on the liver are characterized by injury and deat (necrosis) of isolated liver cells or groups of live cells and by an accumulation throughout the live of large numbers of mononuclear white blood cells Drainage of bile through the tiniest bile channels the *canaliculi* is impaired and *bile accumulates* there and in the liver cells themselves In the more severe cases necrosis of liver cells may be so widespread that death of the patient occurs early in *the illness Usually however complete healing* occurs after a few weeks with no residual altera tion in the structure or function of the organ In a few instances when the disease is protracted in its course or is associated with severe but nonfatal necrosis postnecrotic cirrhosis may result The architecture is then distorted by wide bands of con nective tissue and large bizarre nodules of regen erated liver tissue This postnecrotic cirrhosis is also associated with vascular obstruction *and its* complication just as in the portal cirrhosis of nu tritional liver disease *See* JAUNDICE

Yellow fever is another virus disease affecting *the liver It is spread by certain mosquitoes* and

including all of the blood draining from the intestine See LIVER

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Viral infections Viral hepatitis the most important infectious disease of the liver may be caused by either of two closely related viruses These two agents produce identical changes in the liver but differ in their mode of spread and in the latent period between the invasion of the host and the manifestation of disease In one case the organisms are acquired by the oral route (infected food or water) In the other case they are acquired by the injection of serum from a patient with the disease or carrying the virus The former disease is called infectious hepatitis the latter homologous serum hepatitis Jaundice is the striking clinical feature of viral hepatitis although other symptoms such as malaise abdominal pain and loss of appetite may also be distressing The effects of the virus on the liver are characterized by injury and death (necrosis) of isolated liver cells or groups of liver cells and by an accumulation throughout the liver of large numbers of mononuclear white blood cells Drainage of bile through the tiniest bile channel the canaliculi is impaired and bile accumulates there and in the liver cells themselves In the more severe cases necrosis of liver cells may be so widespread that death of the patient occurs early in the illness Usually however complete healing occurs after a few weeks with no residual alteration in the structure or function of the organ In a few instances when the disease is protracted in its course or is associated with severe but nonfatal necrosis postnecrotic cirrhosis may result The architecture is then distorted by wide bands of connective tissue and large bizarre nodules of regenerated liver tissue This postnecrotic cirrhosis is also associated with vascular obstruction and its complication just as is the portal cirrhosis of nutritional liver disease See JAUNDICE

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geographi ally estri ted t Afri a d t South and Central Ameri a, he e m re ognized and un ecognized f rm it rel t ely omm n J nd ce resulting fr m the nec of li er ell s e po s b f r its ame. H p titi of iral ti l gy oc curs in d g and in p gs, and it is possible th t the lat r d ease, po ci e h pat ti is cau ed by th same irus that is respon ble f infect us hep titis in h m In South Afric an bs ure fatal disease f h se c lled tagge s mal nekte, a sociated ith ev re ec is f the liver and m y also be f vi l origin *See* YELLOW FEVER.

Bacterial infections Bacterial infect ons of the liver are ften seco d ry t nf ct on primary other tes Infe t m y p ad fr m the g ll badder up to the mall bile d w thin the liver prod cing fl mm t th (holangioli is) I fect ns in the t tin l tract, part ularly *ye d tis, m y p ead to the li r th gh the* portal ein. Absce ses ar the us l co equen of this so-called pylephleb tis Alm t any gene alized *fection f th body may in ol e the li eco d* ar ll and in some such as typh d feve bruc llo sis and tul em a, th the rule In lept piro sis the piroch tes espo bl f r th di e produc li er jury and jaundic well as d m age t *other rgans Dog and ther nimals are* fre ently fected by these ame d imila r ganism *See* BRUCELLOSIS TULAREMIA TYPHOID FEVER.

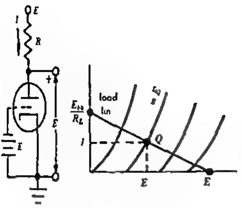
Parasites. Paras t c infections in ol e the li er f a s d animal *Am b c b es e of the li* are the mo t commo a d mo t seri ompli f the int tinal fection by this p ot zo n Am b li er abscesses are u ually gle and may bec me ry large. They m y bec me eco d rily ected with b *ct ria, r may ruptu e int th* pleur l, peri ard al, or peritoneal a ities nd t the l g bo el. The t y blood fl ke known as sch tosomes in de th hi f d d ual baths g in i fected tr pical w t Th y ev n tually find th r ay t *the m ll blood e l* the liver her they mat d where they c u hr nic infl mmat and ev t lly asc lar ob structi n. Other paras ti dise ses of the l e are more comm n mals, b t man is ft i ected incidentally The l *rv l* stage f th d g tapew rm, *E hi us g anul us* h p ed lec tio f th l th i t rm d te h t wh h include man, heep cattle d man th mals. I the l r the, p it prod l rg cy s u lly w th th k l fied w lls Oth m portant para. t s fe ti g the l of man nd l e th l fl ke wh ch h b t and ob struct the m ll b l d t Thes pec fi b t rial. L nd par t d se se a e d sc ed d t l with r d the app pri t h ad gs. *S* Ar ri s.

Chemical agents T h p t t the type f L er injury ed by h m al g t g ted r inhaled nt th body Th e e m y compo d led hepat t s, wh h r p bl f dam g ing the li e The m t mportant a e chlor form a bon t tr hl ride, ph ph rus, and the poison f th mu hroom *Am nit phalloides* They p oduce f tty ecumul ti n d necro s in li r c lls ften w th a di t ncti e patt rn Becau e the li er has great powers f ge erat n omplete he l ng witho t esid al effects may foll w mod ately e e toxic inj ry If t o es re however such in ults m y be rap dly f tal or m y be foll wed by the development f p tnecrot cirrho i Ma y drugs may be injurio to the l er in susceptible or sen iti indi duals. F rtunat ly drug injurie are not often sever enough to be f tal and a rarely f llowed by c rrhos

Obstruction Bili ry cirrhos s is the end esult f pr lo ged ob truct n t the drainag of bile from the li r B hind th ob truction, the b le du ts be c me gre tly dil ted. B le accumulates there in the tiny canaliculi, and w thin the li r cells them sel es. *Bacterial inf ction* f the bile duct s freq t complicat and is ften re urrent E en tu lly ext n i e nnecti e tissue p liferati n re ults, and li er fun tion p gre si ely fails Impa ti n of gallst e n the common b le duct may precip tate u h a p ocess and tumors of th com mon b le duct or pancreas are lso common cau es Bil ary at esia, o failure f th bile du t de *elop in the embryo h s the ame consequ ce* unles urgically c rrectible t leads to b l ary cir s is nd death in infancy or early childhood

Other diseases Ther are se eral obscure dis es which m y i ol e the li r al ng with other *rgan In amyloidos the peculia chemic l* de pos ts charact ri ti of this di ease are l d d wn in the li r a well a in c rta n ther tis es. Th bscur chro infl mmatory disea e called sar coido is mmonly in l es th li e W lson *di ea o hep t l tic lar degeneration,* is ra diso d f coppe met boli m in which the e oc urs cirrh f the li er along with severe dam ge t the central ers us y tem Hemochromatosi d so d f ir n metabol m, is ch r t rized b excess e a um l t of ir in the li er d ther ti es and by the development of eve and ft n fatal cirrho is I prol ged ec rr nt h rt f l r fl t l d m ge may be pro d ed so th t nnect e tis ue scarring oc urs (o g t di cirrho is) This is of minor s gn ficance compared t th effects f the maj card c disease

Tumors. Tumor of the n nmalign t type e are in the li er pt f the neopla m f blood es el called hem gi m s Th se s w ll a les c mm ben gn tum rs of th li er e lly m ll and f l ttl gn fican e M l gn t t mo s f th li r appe t be i r a i g freque cy Th e n t am ble to rgi l tr tm d e p dl f t l S h tum s ally arise f m th l ell themsel es (h p t mas) r f om th b l d t with th l (h langiom s) They are p rt l ly comm in l s with portal r po tne r t rrh d hemochr mat s They h l tile t d ey to p d tsid the li b t



load line d n pl te-c rr t h t cs

tion l t g pl te urre t to plate olt ge a d grid lt ge is t k w a lyt lly A et of pla curre t rves w th load li d aw s I l strated. S e VACUU TUB

W the t be h fi d b the p c d re for d g the l d l e s impl The l d l d n t t sect the plate- lt ge m t a lu equal t E_{bb}, th pl te pply ltage d th tical a t al f plat r nt whi h is eq l to E R he e R_L s th l d re t ce The quiescent pl te urr t I and plate lt g E_b ad at the p t Q wh e the c rve fo th alue of grid b as int r t th l ad l ne

If the t be lf b d by c th de e t the load lin d n by th pr ed r te f ll p ctic l p po e f the ltage d p ac the athode r t r i nl a few per e t f th p' lt g (whi h s ally tr e) How the grid b m t the be d term ned by t l d error

L d l es re l u d with t a t c ts nd oth n nl n r de i to det m n th q nt po t. [H F K]

Loading electrical

The dd t f du t e t t m n l n n der to mp t tra m n h t t c er th eq ed fr q cv b nd Load g c l ften nserted n t l ph e l t p g a loe a l m le, t u te a t th ap ta e f the l nd th m ke the l mped ce m r kel q l t t a p t e S m la h ar ed bet een t n f l d f an tr m S TRA I SION LI F W h l bl s d a g des l d g i ed t th d f th l t bsorb ll p h g th nd, the eby a hie g n n flect ng t Th l) ect u d f th p r fee m y be tapered m t l es wedg f l dielect ic m i l l pe ed ect f r d t t l th t p rtly mpl t ly fill th d the l e S W VE UID When t l loa h rt t g at be des d f l y l n b rted i ws h the t n t g th req ed m i of l ding ne ded for r onance A an example p ct cally ll to rad ha e load ng coil n th nt nna c t b cau e the us al whip antenna i much t h rt f r b adca t band freq e c s S ANTENNA (AERIAL) [J MR]

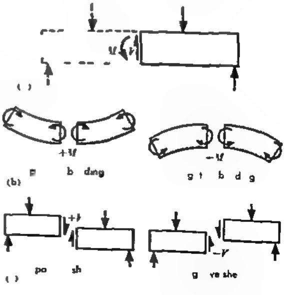
Loading transverse

F ces appl d perp dicul ly to the l ngitud n l axis of a member Tran er load cau e the m mber t bend a d defle t f m it ginal p i t with nte nal t ile a d compres i t ai s ac mpany g chang n cur t re

Co cent ted loads ar ppli d o er a eas le gths wh h a e elati ely small c mp red to the d men o f the memb A gle r ult t fo ce u ed t an lyze eff ts n the m mb r E mpl s are hea y m ch n occ py ng l mit d floo area whe l l ds n a rail r a tie od t tached loc lly Lo d may be t t on ry r they m y b mo i g as with the ca g f c a e h to with tr k wh el

D t but d l ads e f ces pplied c nt n ly e l ge ar s w th u form non nif rm n te ty Cl ely ta k d c tent o wa ho e floors now n wind pre ur are u if rm load A eq lent iform l ad m y epre e t m ltiple cl ly p ed n e tr ted load Variably d s-tr but d l ad ten tie n l de foundat n oil p es es and hyd o t t c pre e.

Bending and shear T an r fo es p d e b di g m m t d tr sv e hear ng f ces t e y ct wh h m t be b l ced by n te al c ple e ti g m ment M nd an ter l tang t al he fo V (F g 1) The e c m p n t f r es e e l t d by f ee-body a aly Th b di g m me t a d r ult nt hea fo e an b exp e d a lyt ally a f nct n of the load a d th d t n lo n g th ti n f om a



F g 1 B m load g ly s. ( ) By f b dy n l y f b m (b) Co t f g f be d g ( ) C t f g t h

cause death by the massive replacement of functioning hepatic tissue by nonfunctioning tumor tissue The liver is probably the most common location for the secondary spread of neoplasms It is the growth of these metastatic tumor nodules in the liver which is the ultimate cause of death in many individuals with cancer of the bowel breast lung or other tissues *See* NEOPLASIA ONCOLOGY [M R H]

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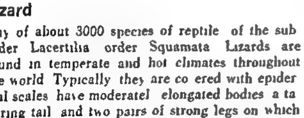
Living fossils

Living species belonging to ancient stocks otherwise known only as fossils They commonly reveal anatomical structures and phylogenetic relationship that at best could only be inferred from the fossils A good example is the mollusk *Neopilina galatheae* dredged from the floor of the Pacific Ocean in 1951 Its known ancestors (family Tryblidiidae) occur in early Paleozoic rocks and were inferred to have been very primitive snails having bilateral symmetry and thus representing a stage preceding the torsion that characterizes all other gastropods The living species prove this inference to be correct but its segmented body also shows that this group constitutes a new class more primitive than the other mollusks ancestral to both the chitons and the gastropods and in turn related to the annelid worms *See* MONOPLACOPHORA

Other examples are the horseshoe crab *Limulus* the opossum *Didelphus* the coelocanth fish *Latimeria* discovered off the east coast of Africa in 1939 and such plants as *Metasequoia* discovered in China in 1941 and the *Ginkgo* whose ancestors thrived with the dinosaurs *See* MARSUPIALIA XIPHOSURA [C O D]

Lizard

Any of about 3000 species of reptiles of the suborder Lacertilia order Squamata Lizards are found in temperate and hot climates throughout the world Typically they are covered with epidermal scales have moderately elongated bodies a tapering tail and two pairs of strong legs on which they run swiftly Most lizards are terrestrial but many are arboreal and several are fossorial or aquatic Degeneration of the limbs has progressed in different groups and a few forms are legless in



The fence lizard *Sceloporus undulatus* length to 5½ in (From E L Palmer *Fieldbook of Natural History* McGraw Hill 1949)

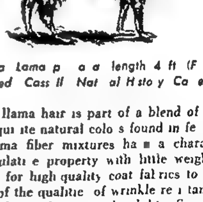
cluding one common species in the United States the glass snake or joint snake

Many lizards are feared as being poisonous but this is true only of the Gila monster and its close relative the Mexican beaded lizard There are both carnivorous and herbivorous species They may lay eggs or produce living young

Lizards are well represented in the United States especially in the South and Southwest Among the more common are the genus *Sceloporus* represented in the eastern states by the fence lizards the genus *Cnemidophorus* best known of which is the swiftly moving six lined lizard the horned toads skinks the American chameleon and the big Gila monster and chuckwalla of the desert *See* CHAMELEON CHUCKWALLA GECKO GILA MONSTER HORNED TOAD SKINK SQUAMATA [J D B]

Llama

An animal allied to the camel and having many of its characteristics but being about one third its size The llama is the traditional burden carrier in the higher parts of the Andes Mountains in South America therefore it has not been bred primarily for its fleece Its hair fiber generally coarse and brownish in color is valued because it may be mixed with the hair of the alpaca an animal of the same species that is raised for its fleece alone Some noils are obtained from the undercoat of the llama



The llama *Lama pacos* length 4 ft (From P M Duncan ed Cassell Natural History Cassell)

When llama hair is part of a blend of fibers it gives exquisite natural colors found in few fabrics Such llama fiber mixtures have a characteristic high insulative property with little weight They are used for high quality coat fabrics to take advantage of the qualities of wrinkle resistance fastness of color and extreme durability *See* ALPACA CAMEL'S HAIR CASHMERE MOHAIR WOOL *see also* ARTIODACTYLA FIBER NATURAL [M D P]

Load line

A line drawn on the characteristic curves of a vacuum tube used to determine the operating range and the quiescent point (the operating point for zero signal input voltage) This graphical construction is necessary because the mathematical func

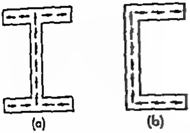


Fig. 4. Shea fl w ( ) I ct d (b) a ch l section.

...hearing tre ses re m s ties of the t ngent al ear f r e distrib ted o er a be m s ti n At a y p t in the beam the ert cal and long tud al ar stresses are q al They a e e o t th boundary urf m and maxim m at the neutral axis. The hear tre.s acc rding to th mmo theory f fl ure is $S = VQ/Ib$ whe e V is t tal vertical f ce, Q tati al m me t bo t the ne tral axis f that area f the be m e t o b tween the level f in estigatio and the t p b ttom f the section, I is m ment of e t a, a d b is w dth In rectangul ecti th d tr bution is p rabol and m imum S t e a d one-h lf tim s the er ge st ess.

Shear flow is the hear f ce per nit le gth along alo g mp e t areas f th secti n The concept f fl s deri d f m the d trib ti n f shear sh r f ces represented by vect rs poi ting i the same d ectio l g the med an line f th n ement and the im lar ty f the xp es on fo mula sh ar to the q atio f r qua tity of liqu d flowing pipe channel (s also TORSION) The d ecti of nit hear force ting in typ al structural sh pe s show Fig 4

Deflection. A beam is said to d rgo deflect n hen the d pl cem t is normal to the o gi l unloaded po m a d s due to c rv tu e prod c d by load Defl tio s may be limited to l ss th m structurally saf al e in buildings to o d cra k ing the ceiling or in m chi e becau e f ne e s ry clearan es.

Elastic n t th c rved hape f the l ngi tudinal e t o dal s f ce wh n lo d p d ce only l ti tres e Deflecti at any p t is found f m th q at n f th c rv

Radius of urv t d pe ds on the m ment d m es f th beam nd constant w th be ding to cir lar rc, h the m me t is c tant Thi ...l bending Curv tur d ar ble moment, d he r f s c t b t addt n l direction.

Statically indeterminate beam I the p esenc of mo r tio mpo ents than c n b det r mined by the eq t s f st t c l beam s statically det rm te. The fir t tep de gn i to find th ti ns. Eq t of tatics are p- lemented by dd t n l q t el t g exte nal f rces t pe d d flect

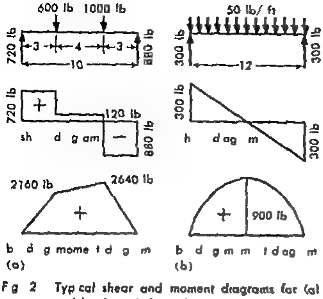
The curv t d c mp ny g st e ses d pe d on the load a d th rest t imposed by the p- ports In mply supp rted beam only ert c l di plac ment is pre ented at the supp rts whe ea when the beam is fixed otat on al.o prevented t the ends S milarly beam with erhanging ends a d beam continuo v r multipl s pports are partially re trained Intr d ct on of the bo nd ry cond t ons de cr b ng the d tions imp sed by the upp ts in the lution of the ba ic diffe en ti l equation f r the elastic curve f rn hes rela t ns between the loads reacti n comp nents and p opertie of the b am Duri g el t behavi r these rel t n t gether w th the equat ons f stat cs al at the indetermi ate eacti ns In ela tic beh io i cau ed by plastic deformations t rit c l s ct n of high flexural stre s when the yield po nt of the mater al i exceeded When a fully plast c co dition is re ch d the secti n acts a a pl ti hinge, with con ta t es ting moment dur ng u re trained rotat n The e known mo- m t at s pport or nterm di te po nts permit d terminati n f the re ct ns by the equations of st ti Ad a tage is t ken of th s nel t a tion n plastic des g

Unsymmetrical bending Lo ds that produce be d ng m me ts n pl es bl que to the prin ip l a es of a tion c u unsymmet cal bending Comp nents of the applied m m nt produce curva ture nd d flect on in pl nes perpendicula t th e axes the st s prod c d by these ompone ts a ting s p rately an be uper mp ed To oid to sio al tw t th blique fo mu t p s th gh either the geomet c enter of ymmetr cal ect n o a part c l r p i t c lled the hear cen ter f r un ymmetrical secti ns

Late al buckli g of be ms s aused by n tab l ity f the comp ss flange which results i l t e l deflect on and tw st f the tion. The ti n r p nd to bu kl f l g columns The c tic l c mp es n t e p d ing buckl ng de pe ds n the sect al dim n s nd typ of l d g wh h in t d te mine the flang tresses nd t s nal rig d ty of the ect ams h g small mome t f i ertia bo t the w k with low to io al t t c are sc ptible t buckling Fo r lled beams, buckl ng res st ce related pp oximat ly t the Ld/bt r t whe e L i sp d i beam d pth a d b a d t width and th ck es f th fl ge, resp ct ly

Bu kli g of be m webs c u d by e d go l mp es n duc d by th omplemen t ry hea st e n th web r by the mbi ed h ar nd be d ng tr s in th web t ng as an dge pp rt d pl t ll u e th web s el t ly th n t te d t bu kle l t rally a erie f w es d ep be m th he st es mu t be ed ced by e d w b th kn ss nf ceme t n the fo m of t ff gles r pl t dded to i crease e t et late l b kl ng

V ble s ect s m k m re efficient f m te l b m by p o d g r t m ment at ll ecti m ne ly qual t the appl d m me t If the e t n m d lus s d e tly as th b d g m me t t es M/Z w ll b sta t t



Fg 2 Typ cal shear and moment diagrams for (a) concentrated loads a d (b) uniformly d str buted load

reference origin The magnitude and distribution of internal stresses associated with the external force system are found by the theory of flexure

Bending moment diagram A graphical repre sentation shows the bending moment produced at all sections of a member by a specified loading The bending moment is the sum of the moments of ex ternal forces acting to the left of the section taken about the section The sign of the curvature is re lated to the sign of the bending moment (Fig 1b)

Typical bending moment and shear diagrams are shown in Fig 2 for concentrated and uniformly distributed loads on a simply supported beam The reactions and moments are found for equilibrium (*see* STATICS)

Shear diagram A graphic representation of the transverse shearing force at all ections of a beam produced by specified loading is called a shear diagram The shear at any section is equal to the um of the forces on a segment to the left of the section considered (Fig. 1c) Positive shears are produced by upward forces (Fig 2)

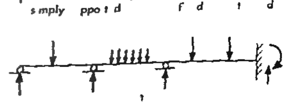
Relationships between shear and bending mo ment that assist in construction of diagrams are (1) maximum moment occurs where shear is zero (2) area in the shear diagram equals change of bending moment between sections (3) ordinate in the shear diagram equal slope of moment dia gram and (4) shear is constant between con centrated loads and has constant slope for uni formly distributed loads Combined loading can be represented by conventional compo ite moment dia grams or by separate diagrams called diagrams by parts

Beams Members subjected to bending by trans verse loads are classed as beams The pan is the un upported length Beams may have single or multiple spans and are clas ified according to kind of support which may permit freedom of rotation or furnish restraint (Fig 3)

The degree of restraint at supports modifies the stresses curvature and deflection A beam is stati cally determinate when all reaction component can be evaluated by the equations of statics Two equations are available for transverse loads and only two reaction components can be found Fixed end and continuous beams are statically indeter minate and additional load deformation relation ships are required to supplement statics

Bending stresses are the internal tensile and com pressive longitudinal stresses developed in re ponse to curvature induced by external load Their magnitudes depend on the bending moment and the properties of the section The theory of flexure assumes elastic behavior No stresses act along a longitudinal plane surface within the beam called the neutral surface A segment subjected to con tant bending moment as when bent by end couples is in pure bending and stresses vary linearly across the section which remains plane Simulta neous shear causes warping and nonlinear stress di tribution The stress is maximum at boundary surfaces of sections where bending moment M is greatest Maximum tress S at distance c from the neutral axis to the extreme element of a section having a moment of inertia I is $S = Mc/I = M/Z$ where $Z = I/c$ is called the section modulus a measure of the section depending upon shape and dimensions Greatest economy results when the section provides the required ection modulus with least area The common theory of flexure applies only to elastic stres Stres es exceeding the elastic limit involve plastic strains producing per manent deflections upon load removal

Inelastic stresses are first produced at surface elements of sections resisting maximum moment A distinct yield point in materials such as struc tural grade steel cau es stresses near the surface to remain constant while interior stresses increase with increasing load Redistribution of stress con tinues until the entire section behaves pla tically The fully plastic resisting moment of a standard I section is about 15% greater than the moment ju t producing yield point at the surface Where small increases in deflection can be tolerated this plastic hinge moment is used in design



Fg 3 Types f beam

creased by u if rmity of st ess and d ctil ty Ca pacity to diss p te energy o erloads by pl tic deformati as is desirable n membe s subj ct to shock impact *See* STRESS AND STRAIN

[W J KR]

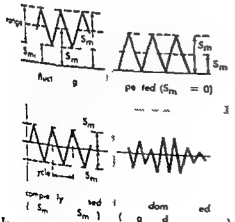
Loads repeated

F es ppl ed m ny t mes ing v rying stresses as the lo d cha ges Rep ted l ad exist rankshafts, xle pri piston r ds rails bad memb rs, and many other m chine and structural leme ts. Repeated l ads nsid ably smaller th similarly appl ed st t c lo ds c use failure by pr g es e fra t re De igns fo re p ed lo d depend on th maximum alue of repeated t hich the mate l can es t lled the fat gue trength, and the m gnit d of lo alized stress co tr t (*see* STRESS CO CENTRATION)

Cycle of stress The riation of tre s d ing e typ al fl t tuo whe the l ad s r peat dly a lied and emo ed or when the l d fluct tes to u u.ly fr m t mpress n is a es ey l (as illu trated) A fluctuat g or pul ating stress ar es betwe m mum and m ni mum alues of th ame ig th cond t n is called pe ted if the stress ed ces t ero in each le. Rev sed stres arie between l of posite gn d i partly rev ed when the posit t esses un q al and complet ly re versed be the oppo te stre a eq l

Stress n tion i descr b d either by the ma um stress, it k d (te n or c mp) and the range f flu tu t on r by the m t dy stress t gth r th the m gnitud f the per mposed alt rn ti g st e s prod g the y l c ar t n. Repe ted l ad upe mp ed on a con stant load, s h s d ad w ght of the tru t re may p od e fl tuatio w thout l E g ank h fts nd parts a l a d axles are sub jected to the rev sed typ cycl l ding wh ch may is f e b ll o s f ep tit s in the l f f the member

Stress raisers D me i al cha g t l discontin i es, r oth r o d ti s causi g l l



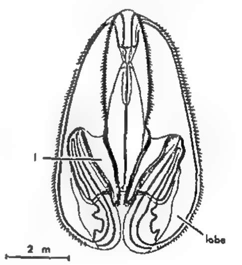
Types of pe ed st

i ed d turbance f th normal stress d tribution w th i rea e of tress that normally produced a e termed stres rai The maximum stress is called a tress concentration H gh local stresses ex t at bolt threads abrupt ch ge f sh ft d am eter n t hes holes keyways fillet wells Int r nal di ntinu ties such as blowholes inclusions se ms cracks d cts d knots n w d v ids in co crete and ariable t ffnes of comp nent o st tue t cause t ess concent atio s At point of c tact f ball or roller bea ings gear teeth r other l al l ad appl tions the tre ma be g eatly ncrea ed Maximum stress is obtained by multiply ng the nomin l tres computed with t rega d to th modifyi g effect of the stres rai er by a t e s once trati n fact This fa tor f und experimentally depend on the type f disc ntinu ity and the pr p rtie f the mate ial under static lo d U tile m teri l rel e es m st of the stress ncent tion by plastic yielding Stre s rai rs ont b te to failure under h gh tres rates and l w temp atu e which t nd t inhib t plastic fl w a d are f gre t import nce und r rep ted lo ds which pr du progre i e f ture c ll d fatigue fail

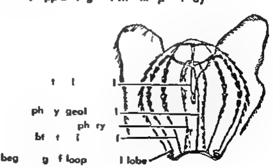
[W J KR]

Lobata

An ord of th Cten phora which the b dy is *helm t haped A pa f la g lobe h ped proc* ea es exte d from the oral d in the pharyngeal



L t cyd pp d t g f M m p l dy



8 l ps mk d

Fig 5 Shear center

all ections and the beam is aid to have con tant trength Dimensions of the ection can be varied by tapering the width and depth or by adding cover plates to a built up section to vary the section modulus Common examples of beams with variable ection are tapered cantilevers plate girder with multiple cover plate forgings and other machine elements A leaf spring is a tapered beam in which uniform stress increases energy absorption

Shear center A point on a line parallel to the axis of a beam through which any transverse force must be applied to avoid twi ting of the ection is called the center of twi t or shear center A beam section twi ts when the re ultant of the internal hearing forces is not in the same plane as the externally applied shear The shear center can be found by locating the resultant of the internal hear forces A channel section has one axis of symmetry and i subject to twi t unle s the external shear passes through a point located e from the center of the web so that $e = B^2h^2t/4I$ approximately when the flange and web thickness are small where B is flange width h is depth of section t is thickness and I is moment of inertia about the symmetrical axi (Fig 5)

Beams on elastic foundation are members subjected to transverse load while re ting either on a continuous upp orting foundation or on closely spaced supports which behave ela tically The curvature deflection and bending moment depend upon the relative stiffness of the beam and upporting foundation Beams of this type include railroad rails on ties a timber resting on le el ground a long pipe supported by closely spaced hanger rods or prings and a concrete footing on a soil foundation The unknown reactive force per unit length of beam is assumed to be proportional to the deflection and the solution of this statically indeterminate problem requires derivation of the equation of the elastic curve whose differential equation is $EI(d^4y/dx^4) = -ky$ where k i the spring constant per unit length of support and ky is the elastic force exerted per unit length of beam Solution of this equation determines the distribution of reactive forces from which the shear and moments can be found See STRENGTH OF MATERIALS [W J KR]

Loads, dynamic

A force exerted by a moving body on a resisting member is called a dynamic or energy load Loads suddenly applied with appreciable striking velocity as when a falling weight strikes another body are called impact loads Such loads are produced by moving machine parts cars on a bridge airplane landing shock falling weights and other nonstationary loading conditions where forces are applied in relatively short time intervals Dynamic load is expre ed in terms of the amount of energy transferred or by an equivalent static load which has the same stress producing effect on the member

Impact or load factor is the measure of the increased static load required to produce the same stress as the dynamically applied load It i thus the rati o of the equivalent tatic load to the weight of the mo ing body Impact affects both the magnitude of the stress and the properties of the material Increa ed strain rates associated with impact increase the elastic and ultimate trength

Elastic behavior If a material or tructure ha sufficient elastic energy capacity as a re i ting member to ab orb completely the energy load through ela tic action and recover completely from the deformation it behaves elastically (see SHOCK ABSORBER) Elastic tres es associated with stored train energy depend on the kind of deformation produced Part of the kinetic energy is dis ipated by deformation of connection friction and inertia effect

Dynamic stres es and deformations can be found by equating externally applied energy to the internal strain energy expressed in terms of stresses and dimensions Dynamic force produced by weight W falling through height h onto a beam or spring is approximately

$$P_{dy} = W + W\sqrt{1 + \frac{2h}{\Delta_{st}}(c)}$$

where Δ_{st} is elastic deflection due to gradual application and c is an inertia correcting factor Stre ses and deflection are found by expressions of the ame form

Inelastic behavior An energy load exceeding the elastic energy capacity of the member produces inelastic deformation For a known amount of energy the dynamic load and deformation can be found approximately from the boundaries of the area under a tatically determined load deformation curve which represents absorbed energy Similarly the inelastic tress produced by impact or the dimensions necessary to limit the stress can be found from areas in the static stress train curve

Toughness is the energy absorbed per unit volume when the material is stres ed to fracture and is represented by the total area under the stress strain diagram Ability to tore strain energy is in

creased by unif rmit f stress and d ct lity Ca acity to d... pate energy e loads by plastic deformations is desirable in members subject to hock im act. e STRES D STRAIN [W.J KR.]

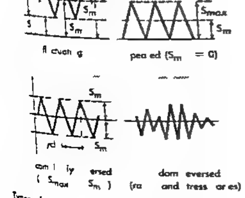
Loads, repeated

Forces m pplied man times aus ng ary ng stresses as th load changes. Repeated l ds exist in crankshafts, axles pring p..t n rods rail bridge members, and many ther m chine and structural lements. R pe ted loads n derably smaller than similarly ppli d tatic loads c use failure by progres e fracture Des gns f r repeated loads depend n the maxim m al e of repeated stress hich the mat rial c n res t called the fatigue ngth, and th magnit d f loc lized stress ncentrations (s e STRE. CO CENTRATION)

Cycle of stress. The ariation f tr d ring one typ al fluctuation when th l d is epe tedly applied and em ed r when the load fl ctu tes continuously f m ten. n to mp es m a stress cycle (as illustrated) A fl tuating o l ing stress aries between m ximum and m nimum alues f the am s gn this c nd ti n is called epeated f th tres red ces t ze n each le. Rev rsed tres aries between lues f ppo ite gns d partly reversed wh n th pposite stresses are qual and compl tely eersed hen th pposit t es are qual.

Stress ariatio is described e ther by the maximum stress, its kind (t nsio compres) and the rang f fluct tion, or by the mean or te dy stress together with th magnit d of th per imposed alternating tr prod ing th cy lc ariation. R peated load p rimposed n c nstant load, such as dead w ght of the tru tur produce fl ctuatio with ut reversal. Engin crankshafts and parts, rails and axles are ubjected to the eversed-typ cyclic l ding, whi m in l billions f epetit ns m the life f th member

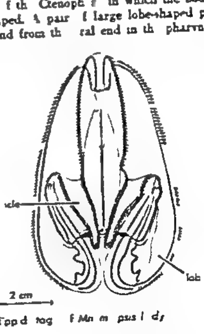
Stress ra sers. Dimensional han es internal discontinuities. the nditions u g local ized disturban e of the normal tress distribution, w th in rease f tress er that n rmall prod ced, are termed tres raisers Th maximum stress is called tress conc ntrati n. H gh local stresses exist t bolt threads, abrupt hange of haft diameter n tches les, keyways r fill t w lls. Inter nal d sc tinu t es ch as blowholes, inclus seams r cracks, d cts and knots in wood. id n c ete and ariable t fness f mpon nt c ntit ents c use stres oncentrations. At poi ts f c ntact f b ll r r ller bearin g ar teeth, r th r local l ad appl at on th t es ma be gr tly in r ased. Maximum stress is obtained by m ltiplying th n minal tress omputed w thout re ard to the mod fy ng effect f the tres raise by tress co centr tion fa tor This fact r f und experim ntally depends n the type f disc ntinuity and the propert es f the mat rial under tatic load. Du til mat rial rel eves most f the tres c n ntrat n b plastic y lding. tres raiser ntribut to fail r under high tress rates and l w t mper tures which tend to inhib t plastic flow and ar f gr t importan e under r peated loads wh h produce pr gres fracture, called fatigue failure. [W.J.KR.]



Types of ed str ss.

Lobata

An rd r f th Ctenoph r in which the body is helmet-shaped. A pair f large lobe-shaped proc esses extend from th ral end in th pharyngeal



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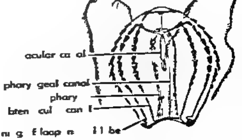


B l psu mk da.

plane A pair of auricles are attached to the base of each process The body is compressed with the tentacular axis being shorter than the pharyngeal axis The ribs are of unequal length with the longest being the subpharyngeal pairs The primary tentacles are degenerate and are replaced by secondary tentacles The canal system is complex Examples of this order include *Bolinopsis Ocyropsis Mnemiopsis Leucothea* See CTENOPHORA TENTACULATA [T K]

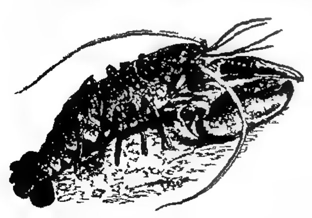
Lobster

A name usually limited to a member of the family Homaridae order Decapoda class Crustacea phylum Arthropoda The family includes nine genera of which only one is represented in American waters by a single species *Homarus americanus* the American lobster

This species is the common lobster of commerce It is a valuable animal supporting an important fishery in the New England states The annual catch has exceeded 100 000 000 lb but due to depletion it has been much less in recent years For example in 1954 the total catch was only 27 000 000 lb 1 000 000 lb coming from the middle Atlantic states and the remainder from New England Depletion has been caused primarily by overfishing and by catching lobsters before they could reproduce Lobsters must now be returned to the water unless they are over 12 in long or have freed the first generation of young

Lobsters are essentially like the fresh water crayfishes in their structure differing mainly in size The average American lobster is a little over a foot in length and weighs about 2 lb The record specimen weighed over 28 lb and was 2 ft long Lobsters are usually dark green with darker spots and yellowish beneath The animal turns red only after it has been boiled

Like the crayfish the female carries her eggs under her abdomen until they hatch A 15 in female may carry as many as 100 000 eggs at a time Mating occurs some time before egg deposition usually in the spring with the eggs being liberated early in the summer The young resemble their parents in form They undergo about 25 molts before



Lobster *Homa us amer ca us* its length s to 2 ft (From P M Duncan ed Ca sell's Nat l H story Cassell)

attaining sexual maturity at 5 years of age The female frees her first brood of young when she is 6 years old and produces a new brood every other year thereafter

In recent years the shortage of the American lobster on the market has brought the spiny lobsters of the family Pallinuridae into commercial prominence There are two commercially important species the California spiny lobster *Panulirus interruptus* on the Pacific Coast and the sea crawfish *P argus* on the Atlantic Coast The latter is a southern form found from the Carolinas southward and in the Gulf of Mexico Together these animals produce about 3 000 000 lb of food annually about two thirds of which comes from the eastern species Both species are 8 in or more in length and are identified by the strong spines on the carapace. *See* CRAYFISH DECAPODA (CRUSTACEA) [J D B]

Location fit

Mechanical sizes of mating parts such that when assembled they are accurately positioned in relation to each other Locational fits are intended only to determine the orientation of the parts For normally stationary parts that require ease of assembly or disassembly for parts that fit snugly and for parts that move yet fit closely as in pigots slight clearance is provided between parts Where accuracy of location is important transition fits are used In these fits the holes and shafts are normally nearly the same diameter For greater accuracy of location the shafts are made slightly larger than the holes such fits are termed location interference fits *See* ALLOWANCE. [P H B]

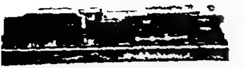
Locomotive

A vehicle supported on wheels capable of self propulsion by converting heat or electric energy into mechanical power for the purpose of moving railway cars over rails It may be powered by steam compressed air electricity oil or gas from volatile oils.

A locomotive consists of a power plant for generating energy a storage compartment for fuel a transmission system for converting energy into mechanical power a system of controls for governing the power developed a braking system for reducing the speed of the train and auxiliaries for lighting heating systems for passenger trains warning systems and devices for increasing unit efficiency The three general classes are passenger freight, and switcher

Passenger locomotives are designed for high speed fast acceleration and light loads The steam locomotive has large diameter driving wheels (69–84 in) electric motor driven units have low gear ratios

For freight service locomotives are designed with slower speed and acceleration than passenger locomotives to pull heavy loads Steam locomotives use smaller diameter driving wheels (63–70 in) electric motor driven units have higher reduction gear ratios



ig 1 Mod rn team passe g r l m t d el ps vdme ffort f 80 000 lb pl d l gth f g e d tender 109 ft t tal w ght 872 600 lb (N k and W st R dw y)

Flexibility i of first importance n a lo om t e switching serv e It mu t m e eas ly in either direction, be able to negotiate h rp urves ha e good id learan e f r mo ement i yards and in industrial a as, d pr ide good i b l ty for the engine cre

Steam locomotive This type c n t f two main parts co nected by a art ul ted joi t. The tender at th t a m nted o idler wheel the cab, fi e box, a d bo l r located the m in f ame mounted the d ng wh els (Fig 1) In an articulated type locomot e, the m n f am re is on tw separ te dr g t ks.

Steam is generated a fire t be b il r using coal r il for f el. H t f om the fire box p s es through boile t bes (F g 2) h at g water to produce steam, h h p ses thro gh ontrol l s into th main cylind r wh e it act p n the driving p st Ea h p to is on ected thr ugh the cross-he d d dri g rod to th dri ing wheels, h h e ected to e h the by s de rods. Th od nection ff the wheel center forming k s that the l r m ement f the pist ses th he l to rot te a d mo the loco t e.

Loc m t peed trolled by a th ottle hich g rn the am t f team e te ing the linder t e time, and th t-off l e which de rmines th tim ng Th se l s a i te n ted th th s-he d the by t m ng th r ning and l g t th m m t of the p ton The locom ti e ever ed by m han m that change the flow f team to the pp site end f the pi t n ylind r

Coal i fed int the fire l x l y l and or a t matic stoker In o l fired l c m ti e oil i f rc d in th ough n zzles Water is f r ed into the b iler by an inject r th ugh a check val e that pre ents the steam fr m ba k ng p The eff c ency of the team eng ne i increa ed by f eheat ng the water bef re it enters the l ler a d uperheating the team before it nter the cyl nders

Electric locomotive Th loc m e c nvert electr c energy prod ced o the t ide to m tive f rce through its ele tric m t rs It ha the ad a tage of perati g fr m an en rgy s urce that is limited only by the rating f the ele tric tran mission system C rre t is p cked up l y third rail ho s or erh ad pa t graph and i either used directly by th m t r or is on rted by transformer m t r lte nators or r ctifier to a f rm usable by them (F g 3)

The power is determined by the number a d characte tic f the elect c m t I it ally the m t r a m tur wa m u t d on the xle now the m t r hu g in the tr k and g ared t the axle by a pin o ge n the armature haft and bull gear n the xle Starting and a celerat on require h gh r nt pe d require high ltage

Locomoti peed i c ntr lled through m t r tr n ti n a d by multiple tep r tors A the peed in ea s th current drops requ ri g higher oltage whi h is btai ed by cutting o t re i t n e nd by t ns ti n Tra s t on i cc mpli hed by ope ing nd clo ing p wer tact rs to f rm e es e s-parallel r full par ll l mot r cir c t Ma imum p ed i l m ted by m tor co tru tio a d gea rat The l m t e s r e ed by re er ng the flow f urrent th ugh the m t r fi lds. An ad ant ge of lect powered l motives is th t tw or m unit an be op rated n multiple by w by t ai l ning thei co trol r it thu multiply ng the r p w r for hea y t ai and te p gr de

Ele t c tr mi on also lends i elf t dynamic r g n r ti e b ak g th r it are ch ged to make gene to f the mot which pump urrent ba k t the l ne o d ipat th ir load in forc d i o led re rs

Diesel locomotive A iabl peed d el n gin wh h bu ns fu l o l p w rs this l mot Th e g e type u u lly u d re four cycle V type f u cy le h e two- ycle V type and pp ed p t n typ They range n e fr m 150–2400 hp h gher hor powe un ts re qu pped with we s pe harge Speed of the n g e c t lled by t e n wh h m asu th q t ty f f el ject d nt the cyl nder th th ttle me ha m i link d t th g rno Se l typ f t m e n g e al use g a hydr ul c nd l tr

G t smis H th d l s n ted t th d g wheel th o gh t a miss of ha ge ble a t s th t p de f r e g d l ng g the peed f th un t.

Fig 2 Flo f hot mb r p d t f m t b f locom tive boil th gh m k h f d p t k

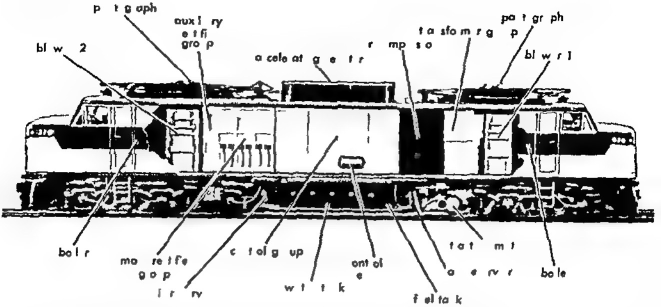


Fig 3 Rect fer type elect ic locomotive for pa senger and freight service has max mum peed of 90 mph s 68 ft long weighs 348 000 lb and develops 4000 hp (General Elect c Co)

Hydraulic transmission Here the diesel engine is connected by universal drive shafts to the hy draulic transmission system mounted on the truck between the two driving wheels One type is an automatic gear shift mechanism with a disengaging torque converter it provides four speeds forward and reverse

Diesel electric locomotive By far the most popular locomotive in the United States is the die sel electric type (Fig 4) Its power is the variable speed diesel engine its transmission the flexible electrical system of generator and motors

The generator driven directly from the diesel engine provides electric power for the motors lo cated on the trucks and geared to the driving axles The generator is separately excited by an auxiliary generator driven by the die el through gear trains or V belt This or other auxiliary generators simi larly driven provide power for auxiliaries and bat tery charging The die el engine ■ started by using the generator as ■ motor with the battery supply ing the power

The air compressor that provides air for the braking system and air operated auxiliaries is di rectly connected to the diesel Fans for the cooling sy tem and traction motor blowers are geared or V belt driven from the diesel In some models the fans are driven by ac motors powered by an ac alternator built on the end of the main generator

In starting power is increa ed by increasing en gine speed After full engine speed has been ob tained motor tran ition and field hunting are u ed to obtain higher locomotive speeds

The speed of the diesel engine is controlled by its governor To balance the power demand of the electric generator and power output of the diesel a load regulator is connected to the governor

Heating for passenger ervice is supplied by a steam generator

The development of the die el has brought a new type locomotive into prominence the road switcher Constructed similarly to the switcher it has suffi cient power for either light passenger or local freight ervice and being adaptable to multiple unit operation it is a versatile piece of equipment

Turbine locomotive This type locomotive is powered by a steam or gas turbine (*see* GAS TUR BINE STEAM TURBINE) The turbine power is trans mitted to the dri ing wheels through an electric transmi sion system

A modern steam turbine coal fired locomotive ■ rated for 4500 hp It has a starting tractive effort

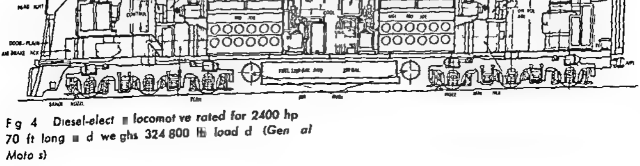


Fig 4 Diesel-elect ■ locomot ve rated for 2400 hp 70 ft long ■ d we ghs 324 800 lb load d (Gen al Moto s)

d 1"000 lb tinu s rating of 144 000 lb at 9 h d m mum peed f 60 mph Its upled length, incl ding ter te der m 161 ft. A water tube boiler pr des te m at 600 psi and 900 F

A odern 1 b rning gas t rbine was put int serv e th U P cific Rail y in 1958 It is rated at 8500 hp f r tra t on t 6000-ft ele ation t 90 F and is des gned for h gh peed l g-di t nce ght run tra k g ha i g a 6-mi 1 14" governing grade. It h t o main its and e 4 000-gal fuel t ailer r all le gth 1 5 ft weight on drivers 828,000 lb, maximum peed 65 mph continuou sti 145 600 lb tra ti e eff rt at 18 h, and dynam c braking fo ce 1 147 000 lb at 22 h.

Th A un t s the a liar es, i cl ding a 6-cylinder diesel gine c pable of p pelling the locom tive and l aded f el tr il r at 20 mph The B unit c t the g s turb ne gener t r pow r unit.

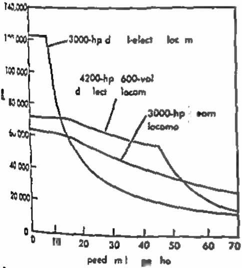


Fig. 5. Typical rv f t ct ff rt f ct f speed f th bo c type f l m t s.

A gear bo bet ee po er plant nd ma n gen tor redu es the 4860-rpm tu b n p ed t 1050-rpm main gener to peed Ea h f th f ur m generat rs d es thre four pole, series-w und traction m t s, mounted in e tru k and gea d to th xles ha ing 40-in.-diamete wheels. At l w peed (0–42 mph) th three mot s of h t u k are connect d n p llel w th on g n at a d one t p f fi ld hunti g at h gh peed (42–65 mph) t s t rs econn t th powe r ut w th tw g t in series nd dri ng ix m tor n parall l. Th s ectı n inc ase th ted hı fr m 800 t 1200 hts a d p vid bett p utilizat n at high peed

Locomoti e characteristics Capacity of l comotive is ted in terms f tr ti e eff rt. St rti g tractiv ff rt indicates loc m ti b l ty t "break" ut a train f m a tand g tart. H e power dev l ped at r t d speed i d ates th t tractive ff rt th t an be expected t a sp eds.

Tr ctı e effort Th forc d lo ed by the power pla t at the d iving wheels i the tracti e ffort It max mum alue l mited l y the unit po er pl nt its u al le alue, by the we ght n dri er a d th r coeffici nt of adhes n t the rail F r starting n dry r l 25 l weight n dri e s is c idered rm l tracti eff rt up to abo t 15 mph F r steam tracti e eff rt i alc l ted fr m th d men n of the l moti e for electric dr e f m th power del red t th m tors (Fig 5)

D awb r p ll Th t f rce d el ped by the l comotive nd a lable at the drawbar f r pulling train is drawb r pull It loc m ti e tr ti e ffort les the f rce necessary to mo e the locomotive.

T n sista c Th ret di g f es c u ed by be ring fr ti n ra l f cti n and w d resi t an e are lumped a train res ta ce. St ti g or b eak away re tance three times th t f tra n re t n e at nif rm peed f 5 mpl

G ade r sista c That f r e r tard ng the m vement f a tr n p a gr d is g ade resi tan e It i mm nly 20 lb p r t n per 1" f g ad

A c l ating sist nc Th f r e th t retard the n rease f train p ed in l d ng inert is a el at g es ta ce To o e me th s, a force necessary t a el ate the tr in we ght nd the r tat f t tat g parts On m le per h ur per sec nd a el rat requires n t f e of 100 lb pe t n of trai

C sistan e That for e resi ting the m ement f a tra n r d r e i alled r e resi t n The type nd fle b l ty f the tr d t r m nes this It s est m ted to be betw en 0 4 nd 0 8 lb p t n f t a n

Cold u th st ta e Mo t ra lr d adju t the r train t n ge d r g c ld w ather t ll w fo effe ts l mped as c ld w th e t n e. The e figure ry f diff nt rail ads an a rag m 5" redu ti n f a ll 10F nc me t dr p bel w 40 F S RAILROAD E GI EERI G [C.A L.]

Locust (forestry)

A name mm nly applied to two trees, the black locu t, *R b ni p ud ca a* and the h ey loc st *Gl dit ia tria nthos* B th of these ommerci lly mp rt nt trees ha podlike fru t s m la t th se f the pea be n S LEGUME.

The bl k lo u t whi h may a he ght of 75 ft, s at in th App l n d the Ozark e gi n nd i n w widely n t r li ed in the a t rn U ted Stat s o th rn Can d and E r p It hara t r zed by odd p te l f gr nt wh te fl m l ke th e f p plant n l ng l ters, flat br wn pod –4 i l g a d p f t p l th rns t the ba f e h l f In wi t th pai d th rn d th po d buds h dd n nder the l f ar mp rt t d ti gu h g fe tur Th w d ha d a d durabl in the so l nd i ed f f p t m n timbe pol and a l d t It th p n ip l wood f r n ul t pi n t l ty pol B e f t w de-

Black locust Robinia pseudoacacia (A H Graves Illustrated Guide to Trees and Shrubs Harper 1956)

spreading fibrous root system which support nitrogen fixing nodules the black locust is well adapted to erosion control and soil reclamation (*see* SOIL CONSERVATION) Many varieties are planted as shade or ornamental trees

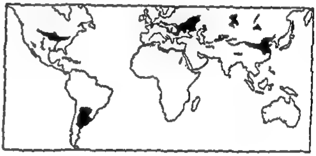
The honey locust which reaches a height of 135 ft is native in the Appalachian and the Mississippi Valley regions but is also widely naturalized in the eastern United States and southern Canada The flowers are inconspicuous but the large brown fruit pods (12–18 in long) are striking The tree may be easily recognized at any season of the year by the branched thorns growing on the trunk or branches The leaves are either pinnate or bipinnate The reddish wood is hard strong and coarse grained and takes a high polish Because it is durable in contact with soil it is used for fence posts and railroad ties it is also used for construction furniture and interior finish Although it belongs to the legume family the roots do not possess nitrogen fixing bacteria The tree is often used for hedges as an ornamental and for shade *See* FOREST AND FORESTRY TREE [A H G]

Loess

An essentially unconsolidated unstratified calcareous silt Most commonly it is homogenous permeable buff to gray in color and contains calcareous concretions and fossils In natural and artificial excavations the loess maintains notably stable vertical faces

Texture and composition Mechanical analyses of loess show that fine sand (grains >0.074 mm) comprises 0–10% silt (0.074–0.005 mm) comprises 50–85% and clay (grains <0.005 mm) comprises 15–45% Variations in published analyses may result in part from the different grade size limits used by the investigators Although dominantly silt and often referred to as well sorted loess is actually only moderately well sorted The silt (and sand) grains are usually angular to subangular Clay occurs as silt size aggregates as coatings on silt grains and as interstitial filling

The silt and sand fraction of the loess has the following mineral composition quartz, 50–70% feldspars 15–30% carbonates (mainly calcite) 0–11% and heavy minerals 5 15% X ray identification of the minerals in the <0.005 mm fraction show abundant quartz plus varying proportions of montmorillonoids illites and chlorites In texture and mineral composition loess is comparable to the average mudstone or shale It is susceptible to authigenic changes such as the transformation of clay mineral formation of chlorites and the movement of soluble materials especially carbonates *See* AUTHIGENIC MINERALS CLAY MINERALS SEDIMENTARY ROCKS



Loess deposits of the world (From A K Lobeck Geomorphology McGraw Hill 1939)

Occurrence and origin Loess is typically developed in areas peripheral to those covered by the last ice sheets in America and Europe Greatest thicknesses (more than 150 ft) occur in the uplands bordering the valleys of the major streams There is a general but irregular thinning of the loess in one or more directions away from each valley Other notable areas are nothern China and Argentina Most of the loess seems to have been deposited during the latest (Wisconsin) glacial stage Little or no loess is found associated with earlier glacial deposits or covering the area actually occupied by the latest ice sheet No loess deposits older than the Pleistocene are known

Many theories have been proposed to explain the deposition of loess The most widely accepted theory is that the materials were transported and deposited by wind Source areas were nearby flood plains and till plains Controversy continues however for some investigators present evidence and arguments in favor of the alluvial origin of some loess Others hold that primary deposits by wind or water have been greatly modified by colluviation to produce loess *See* SEDIMENTATION (GEOLOGY) [C J R]

Bibliography A K Lobeck *Geomorphology* 1939 F J Pettijohn *Sedimentary Rocks* 2d ed 1957

Logarithm

An exponent of a suitably chosen positive number (base) larger than unity Logarithms are of value in mathematical computation and in the equations

ad form has u ed in e pressing natural phenom ena.

The m e ti of nat ral logarithms (ba e e = 2.718) is ually attributed to J hn Napier who p blish d a table of logar thms in Edinburgh 1614 and the title *Mi fici Logarithmo um Can nis De criptio* e en though the fun tio s tabulated by N p er a e merely related to a d not identical th the n tural logarithms.

The m ention f c mm n l garithms (ba e 10) is gener lly attributed t He i Brigg Nap er s share ackno ledged ho e er by Brigg him elf his *Arithm tica logarithmica* n 1624

Theory If $b = n$ her b a po iti e n mber larger than nity then l i called the logarithm of to the b se b and is written $l = \log_b n$ From this definition it foll ws at e th t all po iti e numbers larger than u ty ha e p itive l g thms, all positive mber maller than u ty h e neg tive l garithms, and the loga thm of unity is equal to 0. Si ce $b^0 = 1$ irrespecti e of the alue f b it follows th t th l gar thm f nity i eq al to 0 F m the k n properties of expone tials ex pressed by th elati s

$$b^{l_1} \cdot b^{l_2} = b^{l_1+l_2} \qquad b^{l_1} \div b^{l_2} = b^{l_1-l_2}$$
$$(b^l)^m = b^{lm} \qquad \sqrt[m]{b^l} = b^{l/m}$$

it f ll imm d ately th t (1) the l garithm of a prod ct f t r m e factors is equal t the s m f the l garithms of the fa t (2) the logar thm of the atio of t mbe s is equal t th diffe ence bet een the l g thm f the n merat r and the l gar thm of the denomin t r (3) the l garithm f th mth p wer of a mber th prod t of nd th l ga thm f the number and (4) th l arithm f the mth root of mbe equal to the lo arithm f th n mber d ded by m These pr pert es are e po ble f r the great simpl fica tion in th task of c rrying out n m r al c m putations i l ing m ltiplicatio d s- g umbe t ertai p wers t t g the roots f certain o der of gi e numb It lso follo fr m these p pert es th t in construct g table f l garithms to a c rtai b e fr m th be ginning, the comp te need only mp te the l g rithms f prime n mb s b cause the log rithm f an numbe h ch s n t p im may be obtained from the l garithms of its p ime f ctor by simple per ti ns f dd ti n nd m ltipli tion. *See* Ex po ent

Alth gh y p i e umber b l ger th unity m ght ha been ch n s th ba e of a system of l garithms, a tually two umb s ha e been hose i the n tr ti n f tables of l g ithm na ly th umbe $b = 10$ d the mb de fined as th um f the nfin t se e

$$1 + \frac{1}{1} + \frac{1}{1 \cdot 2} + \frac{1}{1 \cdot 2 \cdot 3} + \cdots$$
$$+ \frac{1}{1 \cdot 2 \cdot 3 \cdots} + \cdots$$

The sy tem of l garithm t the b se 10 s usually referred to as n l g r thms the y t m f l garithms to the b se e is called natural l garithms

Comm n logaritl ms l a e certain obvious ad an tages n t shared by natural log rithms All num bers between 1 and 10 ha e logarithms betwe n 0 a d 1 all n mber between 10 a d 100 ha e loga rithms between 1 a d 2, and so on Thus the integral part of the c mmon logarithm of a number la ger than u ity i one init less than the number of digits bef re the decim l point Thi integral p rt i called the *haracteri tic the de mal part* i called the mant sa Similarly becau e the m mon l garitl ms of 0 1 0 01 a d 0 001 a e -1 -2 and -3 it f llow that the l garithm f a number sm ller than unity having p zer fter the deci mal point may be expres ed a the sum f a nega ti e char cter tic eq al to $-(p+1)$ d a po i t e m ti sa

Natural logarithms Becau e the number e = 2.718 the b e of the system of nat ral log rithms is irration l th t is it cannot be expres ed s the rat o of two integers (a d theref re when ex pres ed as a decimal umber it in ol es an i finite number of decimal with no repeating gr ups of d cimal) It m ght seem odd therefore that it has been hosen the b e of a sy tem f logarithm The primary moti ation f r this choice lies in the fact that the lutions of numer us problems in appl ed m themati are m t natu ally expres ed in te m of powers f e Thu for inst nce the sol tions of the probl ms of eq ilibrium f a flexi ble cable, the t ient fl w of electric current in a rcuit a d the di i tegrati n of radioacti e ele ment r expressed in terms of e^x where x is ei th r po iti e r negati e and depends on the physi cal pa meter of the probl m in qu t n Thus, the tabulat f the f ncti n e^x f r both p iti e and negati e l es of x was an ind sp nsable aid obtai g the sol t ns of many phy ical prob lem Beca the logar thmic f t n i the in e e f the e p ential f tion a table of n t ral l gar thm can be nstructed w th relati e ea e f m a t ble of e^x by the process of e ter p l t on. An ther moti at n for constructi g tables f natu al l garithms th fact that natural loga thms a se th integr t n f q t ent of poly m als nd of f ctions wh ch may be approx mated by q otients f p lynomials Indeed it is a well kn w fa t th t f th o ts of a p lyn mial $Pn(x)$ a e k own so th t $Pn(x) = a_0(x - x_1)(x - x\ )\ (x - x\ )$ d if $Q(x)$ i p lynom al of deg smalle th n then the quotie t $Q(x)/P(\ )$ may b d i the f rm

$$\sum_{k=1} \frac{A_k}{x - x_k}$$

wh n the A may be ly d t rmined A cord i gly

$$\int [Q(\ )/Pn(\ )]\, dx = \sum_{k=1} A_k \int \frac{dx}{x - x_k}$$
$$= \sum_{k=1} A_k \log (x - x_k)$$

Table of logarithms

Nu nber	Nat ral l g r thm	C nm log thm
0 01	86 − 10	− (8 − 10)
1 0	0	[illegible]
e = 718	1	0 4343
10	303	1
1000	6 909	3

Relation between logarithm bases Let l_1 be the known natural logarithm of a number N What is the common logarithm of N? Clearly $N = e^{l}$ and therefore $\log_{10} N = l_1 \log_{10} e$ Since $\log_{10} e =$ 0 43429 (to five decimals) it can be concluded that natural logarithms are converted into common log arithms by multiplying the natural logarithm by the factor 0 43429 which is called the modulus Similarly the common logarithm is converted into a natural logarithm by division by the modulus 0 43429 or multiplication by [illegible] 303

Logarithms of complex numbers Since b^{l} is positive when b is positive negative numbers have no real logarithms Nevertheles Euler s famous formula $= \cos\theta + i \sin\theta$ where $i = \sqrt{-1}$ makes it possible to define not only the logarithm of a negative number but also the logarithm of a complex number Indeed any complex number $a + ib$ may be written in the form ρe^{i} where $\rho = \sqrt{a^2 + b}$ and $\theta = \arctan(b/a)$ It follows that the logarithm of a complex number $a + ib$ is a complex number whose real part is the logarithm of its modulus ρ and whose imaginary part is its phase (or argument) θ Because $e = e^{i}$ it follows that a complex number has an infinite number of logarithms given by the relation

$$\log (a + ib) = \log \sqrt{a + b} + i(\theta + 2n\pi)$$

where n is a positive or negative integer

As previously mentioned the evaluation of nat ural logarithms may be based on inverse interpola tion in a table of e For small values of x positive or negative one may use the expansion

$$\log (1 + x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \qquad + (-1)^{+1}\frac{x}{n} +$$

This expansion may be derived from Taylor s series

$$f(x + a) = f(a) + \frac{x}{1} f(a) + \frac{x^2}{1 \quad 2} f(a) + \qquad \frac{x}{1 \quad 2 \quad 3 \quad m} f^{( )}(a) +$$

by writing $f(x) = \log x$ After a sufficiently accu rate table of $\log (1 \pm x)$ for $x = k10$ $k =$ 1 2 3 9 and $n = 1$ 2 3 N where N is suf ficiently large (perhaps 15) has been computed this table may be used to compute the logarithm of any number From the above expansion for $\log (1 + x)$ it is easy to derive the expansion

$$\log p = \tfrac{1}{2}\{\log (p - 1) + \log (p + 1)\} + S(p)$$

where

$$S(p) = \frac{1}{2p^2 - 1} + \frac{1}{3(2p^2 - 1)^3} + \qquad \frac{1}{(2n + 1)(2p^2 - 1)^{2+1}} +$$

which has the virtue that $S(p)$ converges quite rap idly Thus for $p > 10\,000$ the error resulting from neglecting all but the first term in $S(p)$ is consid erably less than 10 See e NUMBER THEORY NU MERICAL ANALYSIS [A N L]

Logging (forestry)

The first step in lumber manufacture is harvesting trees from forests in the form of logs and deliver ing the logs to a sawmill See LUMBER MANUFAC TURE

Equipment Felling trees elected for cutting is accomplished with hand saws or by power aws The chain type gasoline powered saw with cutting teeth in a chain moving rapidly around the blade is the most widely used (Fig 1) Trunks of felled trees are severed at log length intervals to the point of minimum merchantable ize or quality in the top Most log lengths are 12 14 and 16 ft corresponding to the tandard lengths of lumber used in general construction although other lengths are cut for special needs

Logs are skidded short distances over unim proved terrain to an assembly yard or a loading point on a logging railroad a truck hauling road a winter sled road or a stream in which the logs an be floated or loaded on barges This requires considerable power as do all subsequent steps in logging For example a longleaf pine log 16 ft long and 18 in in diameter weighs 1500 lb Logs are skidded by mobile power units such as a hor e or a

Fig 1 A logg f lling a l ge t w th a m ch n pow r aw (Ph t g aph by Hom l te C p)

tracto r by t tı ary de l pow r u it with drums d bles. The m bile u t goes to th l gs a d pull them to the ro d ide. With a st tı nary un t, l are fa te ed to the nd of a c ble and a ıt nd the drum th l g a e pulled t A ıd ariety of types nd ze of kidd g equ p-ment b been pe fected t meet ar at n f umbe ze, t rr ı and de ty f the ı nd t be ut.

Methods. Att chme ts ed t fa te l gs to k d d g dev es re to gs ımil t ee to g or h k rs *resembl* l p oo es pl ed a d the ds f l Whe the gr nd ı too swampy to pport anım ls t t rs or too teep c ble k d d g ıs ed The h gh fi ed c t f cable skidding ınstall t s qu s m ım m d ly log lumes *I 50 000 ft* 10-ye r perat ng life nd ta d gıng 10 000 ft/ e. The mple t f m f bl kdd g c t f d agg g log n the d t th m h ne w th or without a cable h l A m h m wid ly ed method ın th high l d w th t h l With t the p ll g c ble s led from th p ll g d m th gh a p lley block fa t ed 30–150 ft up t ee r p r and th n t to th k dd g a. A l ghter c ble gged to p ll the k dd g able rap dly ı t after a load ha bee k dded Whe k ddı g has been mpleted ın s h ar a, the r haul block re el ted and th k dd g l m ed t the dj ent seg ment. I ll bl kiddı g m lar p tte n ıs f l lo ed, that th t f m g ar nd the rel until the t with l g has be n c e ed A h d bl st et hed betw a h d par t the po t d suc e e tail pa at th f r edge f the kidd g lso used wh th kidd g d t ce d th t at wh h the high le d m thod ffe t The e e l o e he d method b t all th k dd l ne ext d up the h d par thr gh a t ll y block th t ride the ain c ble t et hed bet ee the and then t th gr d h l gs be fa te ed t ıt The kidd g lın tted al g the sk dd g tr l by the k dd man s ted by gnal me A l d f l gs ı p rtly r wh lly ed bo the g nd d th p ll d by th t ll y t th h d p r C d kidd a be used ffecti ely f r d s ta es *f 300–400 ft* Th h gh lead meth d s ef fecti t 400–800 ft, d p d g on the h ght f th high l d block. Ov he d bl k dd g h w ever b u d p t ¼ m le or f rthe

Wh t rr p rmits m b l p we k dd g ı lly f ed b u f ts t l ty d be se t p rmit l g d tre d y ng t p bl f g ı g t mer h t ble ze wh a bl kiddin ı q te de tr t t ll t trees th k dd g A m l logg ng h d s ppear d f m ll b t the m lle t t ns T t th t w h mply d g l g n th gr d T t t g h f w de f ızes e ed t ly f r k dd g ı all p f th try They d pt bl t l g t m ll l gs, t p m ddy t d t w ed gr d Th h pp rt n l t d pulley th ugh which the cable fr m the tra t r winch ıs extended to the l gs. Wl en they are fas-tened to the cable they are pulled up under the arch a d th n dragged with the r front ends ff th gr nd t red ce fr ct n A c awler tr ad arch needed f r l a y l ad and *teep r ı dd gr und* Wheel d agric lt ral type tra tor re u ed ın the E t and So th on firm ground f mall l Trac t r *kidding d tanc re b t pra tic l c n idera* tio s u u lly lımit kiddı g t ¼ mil For l ger k dd ng a ın getti g l gs o t of wide r bot t ms l g wag n with wid wi eel t ad or w th rawl r tread a e p lled by tract r

Loading. Aft r log h e bee kidded t th t an port t n y tem th y re l aded n h cle r put n wat r f r tran port t the m ll Lo ding *methods ra ge f om pulling the ro d l up skid* nt ehicles with a ım l r light tr ct rs t h ghly peci lized ra fro d r tr ck l ader E cept fo roll g log e k ds to wag r tr k p h g them ınt st am l g l dı g de ce re des gned t *lift* log and dep ıt them n a co ey a e Th r qui s a erh ad pulley block a cable, d powe unit wıtl d um or a draw l ar p ll of t am r *tra t r Loading* abl ar at ta hed to e hang g f m or gın p l s t guy l ne o are placed ın the nds f m able boom The more e satile l aders are self pr p lled w th f ll sw gı g booms which pe m t l d ng truck *r c rs from any poı t (F g 2)* Statı ary types m t load fr m log once tr ı p t Tl at t hm t at the end f a lo d ng ble f f tening to l gs may b t gs able loops The m t re-ent dev l pm nt ıs boom w th a comp essed aır t ng grab pe ted by the l der th t el minates the hazard s j bs of the t g ho k r d top lo der

Special transportation systems *Larg f re t* ea req re pect l tran portation sy tem f r haul g l g ın deq te of me t upply mill

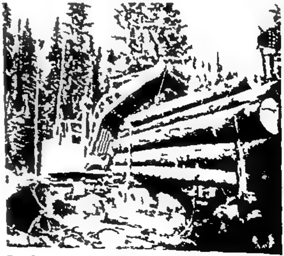


Fıg 2 A lf p p ll d h vy-d ty l g lo d l d g p d f l g ld h f t k h l p t d *(Ph t g ph by W sh gt l W k S ıll W h gt)*

Table of logarithms

N mbe	Nat al l g rttl m	Common log thm
0 01	586 − 10	− (8 − 10)
1 0	0	0
= 718	1	0 4343
10	303	1
1000	6 909	3

Relation between logarithm bases Let l_1 be the known natural logarithm of a number N What is the common logarithm of N? Clearly $N = e^{l}$ and therefore $\log_{10} N = l_1 \log_{10} e$ Since $\log_{10} e =$ 0 43429 (to five decimals) it can be concluded that natural logarithms are converted into common logarithms by multiplying the natural logarithm by the factor 0 43429 which is called the modulus Similarly the common logarithm is converted into a natural logarithm by division by the modulus 0 43429 or multiplication by 2 303

Logarithms of complex numbers Since b^l is positive when b is positive negative numbers have no real logarithms Nevertheless Euler s famous formula $e \quad = \cos\theta + i \sin\theta$ where $i = \sqrt{-1}$ makes it possible to define not only the logarithm of a negative number but also the logarithm of a complex number Indeed any complex number $a + ib$ may be written in the form ρe where $\rho = \sqrt{a + b}$ and $\theta = \arctan (b/a)$ It follows that the logarithm of a complex number $a + ib$ is a complex number whose real part is the logarithm of its modulus ρ and whose imaginary part is its phase (or argument) θ Because $e \quad = e^{(\quad)}$ it follows that a complex number has an infinite number of logarithms given by the relation

$$\log (a + ib) = \log\sqrt{a + b} + i(\theta + 2n\pi)$$

where n is a positive or negative integer

As previously mentioned the evaluation of natural logarithms may be based on inverse interpolation in a table of e For small values of x positive or negative one may use the expansion

$$\log (1 + x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \quad + (-1)^{+1}\frac{x}{n} +$$

This expansion may be derived from Taylor s series

$$f(x + a) = f(a) + \frac{x}{1} f(a) + \frac{x^2}{1 \quad 2} f(a) + \frac{x}{1 \quad 2 \quad 3 \quad m} f^{(\,)}(a) +$$

by writing $f(x) = \log x$ After a sufficiently accurate table of $\log (1 \pm x)$ for $x = k10$ $k =$ 1 2 3 9 and $n = 1$ 2 3 N where N is sufficiently large (perhaps 15) has been computed this table may be used to compute the logarithm of any number From the above expansion for $\log (1 + x)$ it is easy to derive the expansion

$$\log p = \tfrac{1}{2}[\log (p - 1) + \log (p + 1)] + S(p)$$

where

$$S(p) = \frac{1}{2p^2 - 1} + \frac{1}{3(2p^2 - 1)^3} + \frac{1}{(2n + 1)(2p^2 - 1)^{2+1}} +$$

which has the virtue that $S(p)$ converges quite rapidly Thus for $p > 10\,000$ the error resulting from neglecting all but the first term in $S(p)$ is considerably less than 10 See e NUMBER THEORY NUMERICAL ANALYSIS [A N L]

Logging (forestry)

The first step in lumber manufacture is harvesting trees from forests in the form of logs and delivering the logs to a sawmill. *See* LUMBER MANUFACTURE

Equipment Felling trees selected for cutting is accomplished with hand saws or by power saws The chain type gasoline powered saw with cutting teeth in a chain moving rapidly around the blade is the most widely used (Fig 1) Trunks of felled trees are severed at log length intervals to the point of minimum merchantable size or quality in the top Most log lengths are 12 14 and 16 ft corresponding to the standard lengths of lumber used in general construction although other lengths are cut for special needs

Logs are skidded short distances over unimproved terrain to an assembly yard or a loading point on a logging railroad a truck hauling road a winter sled road or a stream in which the logs can be floated or loaded on barges This requires considerable power as do all subsequent steps in logging For example a longleaf pine log 16 ft long and 18 in in diameter weighs 1500 lb Logs are skidded by mobile power units such as a horse or a

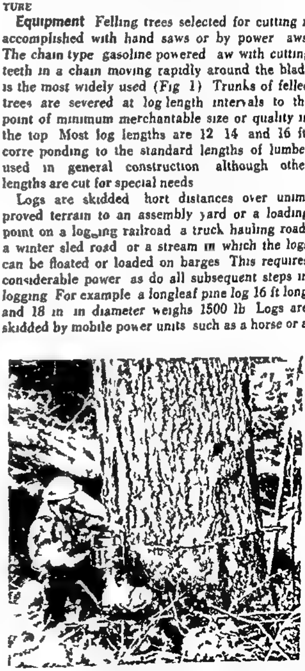


Fig 1 A l gg f ll ng a la ge t ee w th o ne ma cha p wer saw (Ph tograph by H m l te Co p)

ll X is Y (un ersal affirmat ve judgm nt)
o X is Y (un versal negat e judgment)
ome X is Y (particular affirmati e judgment)
ome X i n t Y (partic lar negati e judgment)

The three n ten n co tain altogether three , S (the subject f the concl i n) P (the cate of the oncl si) nd M (the middle) th t oc r ea h of the prem es P is d th maj r term, S the m nor term a d a i e n called maj r or min r cording as it a ns P r S e pect ely It is by virtue of the lle term M hi h occurs n both prem es l tion b t een S nd P may be a erted s the th ee statem nts

\ p f sors rich
All hands m men re pr fessors
No handsome me are h

m a syll g sm which M tands f r p ofe ors for rich, d S f r ha dsome men Th n ticu r yll gism s alid (th t s, the nclus n is nseque ce of the prem ses) d hence the alid y of yllogism s ee t be independe t f the uth fals ty of ts conclu Not ce th t the i r p em e, min r premise a d ncl on f he abo e syllogi m e tatements of type (E) A) (E) especti ly

The f r fig s of the syllogism are epre ented by

(I)	(II)	(III)	(IV)
MP	PM	MP	PM
SM	SM	MS	MS
SP	SP	SP	SP

Ea h ymb l MP SM d so on st nds f r e of th f stat ments (A) (E) (I) (O) fo e am ple, MP might symbol ze the t t m nt No M s P Hence e ch figur has 4 = 64 p s bl forms, and c nsequently th r r 4 4 = 256 n ssible f rm f r a yllogi m The g e t att t g en the yll gism by l gicians f the M ddle Ag re ulted est bli hing th t o ly 19 of the p ss bl 256 f rms th t yll gi m m ght take are dm ss bl (th t s, y eld l d lu io) It h uld be ted th t th res lt they bt ined rrect pro ded ccept the A ist tel an p ciple that the tatem t All Y s Y" impl s that The e ar X's. It was also maintain d th t No X is Y im plies th t Some X s not Y" Th s acc ding to ea ly l gic ans un e sals h e t ti l impl cations. Modern l gi i n d t t k th p t f ew This esult i lim n ti g 4 f th 19 adm s ibl f rm (moods) Thr e-syll ble m em n c d er c ed whi h th ow l d ted m der th e mb at o f th tateme t (A) (E) (I) (O) th t e lt d l d yll g ms F r fig (I) th y a B b C l t D rii, F rio f figure (II) C re C m t s F t no B oc figur (III) D tisi Feris Dis mis B d D pti, F l pt figu (IV) C lem s F sis n, Dim tis B m l p and F s p Th ll tr ti yll g m g e bo e Cel t, fig u e (I) The four m ods that depe d for their va lidity on the cla sic l a sumpt on that uni ersals imply existe ce (and wh ch mu t be el minated if that assumpt n is n t made) are Dar pti, Bam lip Fes po and Felapton

The syllogism is n w of little more th n hi to i cal interest Its lim tations were recognized q te early for it w s cl ar that few of the inference needed in mathematics could be put in yllogistic f rm As rem rked by Hans Reichenb h It i only the n mbination f a logic of functi ns of se eral va able with the logic f pr po itio th t le ds t the full u derstand ng of co versational l nguage s well as of mathematics.

Propositional calculus The unit of the pr po i tional calculus is the propo ition which may be de fi ed the meaning f an indicati e or declarati e entence Each proposit on h s a truth alue it i either true or false in the classical logic, but may assume other truth values (f r e mple, uncertain) in some of the ew l gics Thus

To err i human

is prop sit n where

Lead us not into temptation

n t a propos tion It is con en ent to use let ters p q r nd n on to de ote prop sitions P op ition are comb ed by logical connec ti e to form other propo tions Chief among these a e (1) egati n (the negation f a proposi tion p symbolized by p may be formed verb lly by wr t g It is n t the n e that" befo e p) (2) conj nction (a binary operat on ymbolized by or & for example, p q r ad "p and q) (3) disju cti (a bin ry per t on ymb lized by + or f r example p q read p or q") (4) implicati n (a b ary operati ymbol ed by ⊃ or → for ex mple p → q read p implies q) (5) equi lence (binary n ati n de t d by ≡ for xample p ≡ q read "p n equi alent t q" mean th t ach n p ition implies the oth r) The p opos t p q ert that both p nd q are true It is imp rt nt t n te th t the d juncti e o alway ed in the cl e en n that i p q rts th t t least ne f the propos ti n p q tr e nd m y be both In ddition the mean ing f impl at in l gic diff m rkedly f m th ord n ry e e of that term The propos t on p → q as erts mer ly that it ot the a th t p i tr d q i fal e th t s, n class c l l gi p → q mea s th t eithe p i f l e o q is true. Thu ny false pr positi (f r ample Napoleon B aparte w s b rn in the year 1600) impl y prop t wh te er It mpl s, New Y k i a large ty Cleop tra w s q en of Fran e. S mil ly y tru n p siti n mpli d by y pr p it n what e In an mpl ti n p → q p is called the ant ed n nd q th co seq t. Th l gi l c n t es ti d d abo e n e ample of log l n t t They r not nd pe dent n t s. Impl ti n m y b defi ed in t rm f g ti nd nj n t n and th i

with daily capacities ranging from 50 000 to several hundred thousand feet per day Standard gage logging railroads with such volumes are practicable They consist of main lines with spurs that ultimately cover all the property Spur spacing depends on the topography and the skidding method but it usually averages about ½ mile Diesel or steam locomotives move empty log cars to the loading area and assemble trains of loaded cars for hauling to the mill Spur tracks are removed after the logs have been loaded out and relaid on new spur locations

At present however most log hauling is by motor trucks ranging from 2–100 tons of gross vehicle weight The larger types are used only on private roads as they far exceed permissible weights for public highways Logs may be transferred from one transport method to another such as from a large truck to a small one for public highway haul or from truck to rail or to water for floating or barging

Where available water transportation is desirable because less power is required to move floating logs When northern freshets in the spring flow from the logging area to rivers that in turn flow to mills stream driving is an economical and effective means of log transport Logs are floated unconfined but are kept from jamming in narrows or stranding on shores by a crew that follows the drive downstream Water from melting snows is held upstream by small dams and released when the drive starts to flush the logs downstream Stream driving can be used only in nonnavigable waters In quiet waters logs can be floated confined within a boom of floating logs fastened end to end that serves as a floating fence In navigable rivers and inland waterways logs are transported fastened together in rafts which are pushed or towed by tugs Barges also can be loaded with logs and then moved by tugs or river craft from loading points to destination The logging operation is completed when the logs are delivered to the mill or a shipping point

Prelogging In western forests of large trees prelogging is sometimes done in which the smaller trees are cut and removed with light tractors or even teams before the large trees are logged by cable systems or by heavy tractors This reduces waste caused by breakage of the smaller trees Integrated logging means the harvesting of several kinds of products from the same stand at about the same time They are removed either prior to subsequent to or at the time of logging and may include poles pulpwood veneer bolts cross ties or other products [A E W]

Bibliography *See* FOREST AND FORESTRY

Logic

The subject that investigates formulates and establishes principles of valid reasoning

The first attempt to investigate systematically acceptable modes of reasoning was made by Aristotle in whose *Organon* reasoning was recognized as the subject of a special science In that work he formulated three basic laws of thought (1) the law of contradiction (no proposition is both true and false) (2) the law of excluded middle (each proposition is either true or false) and (3) the law of identity (each proposition implies itself) Advanced as his views of logic were it seems doubtful that the idea of axiomatizing it ever occurred to him despite the success of his contemporary Euclid in organizing geometry That aspect of logic which enunciates or establishes valid reasoning (rather than merely investigating it) began with the publication in 1854 of George Boole s *An Investigation of the Laws of Thought* The partly abstract treatment of logic presented in this work initiated the completely abstract developments that were to follow In it the laws of thought are regarded as mere conventions which like the postulates of euclidean geometry might be modified or even rejected to create new logics The only requirement that a new logic must satisfy is the one demanded of every deductive system—consistency Just as different geometries are useful for different purposes a logic that is appropriate in one environment might not be so in another There are a growing number of competent individuals for example who consider that any logic containing Aristotle s law of excluded middle is not suitable for mathematics

This article does not attempt to discuss all of the topics that are traditionally grouped under the term logic Because it is assumed that the reader s principal interest in the subject is to acquaint himself with some of the principles for testing inferences to acquire a knowledge of the use of formal procedures in clarifying arguments and to learn how important parts of logic have in recent years been developed axiomatically the classical theory of the syllogism will be examined and the deductive theory of truth functions (the calculus of propositions) will be presented in some detail For the most part the discussion will be limited to what is called symbolic or mathematical logic for a special set of symbols is employed to exhibit in the clearest way the (at times) complicated logical relations involved The advantages of a thoroughgoing use of a good symbolization are enormous It is by such means that modern logic is able to solve problems that were quite beyond the power of logicians of an earlier time and to render some of the achievements of those logicians almost trivial by comparison

The syllogism The formulation of the syllogism is contained in Aristotle s *Organon* It had a great fascination for medieval logicians for almost all their work centered about ascertaining its valid moods The three characteristic properties of a syllogism are as follows

1 It consists of three statements the third one (conclusion) being a logical consequence of the first two (the premises)

2 Each of the three sentences has one of the forms

establ sh d, and ınce functı n ıs n t ngent ıf and ly ıf ts g tıo s, elf ı con tent f nd only ıf ıts n gatıo s ta t l gy a d a taut l gy pro ıded ıts gatı ı lf n t nt, a kn wledge of the chara t r f the n gated f nctıon ol es the pr b- lem. The meth d makes se of the so-called De M gan formulas $(p \quad q) = p \quad q' \quad (p \quad q) = (p \quad q')$ ın hı h the gn = s gn fı that an e p e ı n ppearıng o ı s de of t m y be epla ed by the e p es o app a ıng o the ther s de) nd th Bool n xpan f a t uth fu ct o This ı an e pa th t h b ts all of the o junctı e possıbıl tıes f r tr th alu *T* ıt a dı j nctı n f m tually e lu e (c mpat ble) juncts F r ample, p q as m s truth alue *T* ıf and nly f the f ct n $(p \quad q)$ $(p \quad q)$ $(p \quad q)$ does. The l tter f n tıo ı th B lean expa f p q The m thod of n g t on can b ıll s tr ted fır t by s d rıng th m truth fu ct on $(p \supset q) \supset (q' \supset p')$ an lyzed by the m trıx method. W t g

$$[(p \supset q) \supset (q' \supset p')] = (p \supset q) \quad (q \supset p')$$
$$= (p \quad q) \quad (q \quad p')$$
$$= (p \quad q) \quad (p \quad q)$$

and otıng that $(p \quad q)$ $(p \quad q)$ a the c j c tıo f a p po t n d ts gat s lf co tıent, ıt f ll s that $[(p \supset q) \supset (q' \supset p)]$ s lf ın ıst t, and so $(p \supset q) \supset (q' \supset p)$ s tautol gy A co d example u g the Boole n exp n f p q t

$$[(p \quad q) \supset q] = (p \quad q) \quad q$$
$$= [(p \quad q) \quad (p \quad q') \quad (p \quad q)] \quad q'$$
$$= p \quad q'$$

Cl arly th truth f t p q' s contı ge t, and nseq e tly so s th f tıon $(p \quad q) \supset q$

Tautologies and forms of argumentation On truth fun tı n *T* ece arıly ımpl es a ther *T* p or d d th *tr th functıo* $T \supset T$ ta t l gy For xample $(p \supset q) \supset (q' \supset p)$ a t tol gy and so th truth f t $p \supset q$ es rıly m plıes the truth fun t n $q \supset p$ O the other h d ther f tho e t o truth f tı m t t l gy and so th ımpl tı th y hıb t e not eces- sary ımpl tı ns. Valıd f rms of g ment tı are based th tı n f ece y ımpl cat T o h f rm e kn wn t l ss cal l g as (1) *m dus p d po ns* a d (2) *modus tol l d toll ns* The fır t tat th t f n ımpl atı n $p \supset q$ d ts nter d t p ar a ert d, th n the conseq t q m y be ssert d th t th t th f ctı $(p \supset q)$ p ec a ly mpl q Th s establ hed by p g th t th truth fun t $[(p \supset q) \quad p] \supset q$ ta t l gy Th *modus tol l nd t ll ns* f rm f a gum t perm ts th den l f the anteced t f e ted mpl t n wh n ıts co seq e t d n ed. Th l dıty of th rgu ment t po the t t l gy $[(p \supset q) \quad q] \supset p$

A comm n fallacy (f llacy f the con equent) ıs to a ert the antecedent of an ımplı atıon who e c n equ nt l a bee as erted This ıs not perm s- ıble nce the tr th functı n $[(p \supset q) \quad q] \supset p$ ıs t taut logy Although s ch an argument ıs l gically unw rranted t ı frequently ı ked ın t t ng e p rımentally a hyp the ıs p F r ıf q fol lows from p numer us ın tances of the alıd ty f q re somet mes taken t fur ı h tr ng evıde ce of the al d ty f p

A t ad tı nal form of a gumentatı n known a the d lemma *ıs an applıc tıon f m dus pone do p nens o modus t ll ndo tolle s* Consider the foll w g example

(1) If I peak the tr th men w ll hate me ıf I l e, the god will hate me
(2) I m t *eıthe speak the truth or lıe*
(3) Therefore e ther me will hate me or th gods wıll hate me

The f rm f th d lemm ı as f llows

(1) $(p \supset q) \quad (\supset)$
(2) p
(3) $q \quad s$

Th arg me t al d by *m dus p end po ns* f r ın e premı e (2) affırm the a tecede t of at le t n of the mplıc tı n f premı e (1) at lea t *e of th nseq ent may be asserted* wh h what the cl ı n (3) d s

Deductive theory The ınte t f th se tıon ıs t ketch the p cedu by whıch all ta t log es d d cıbl f om a et f *just four of them* Th s ıs anal go to wh t ı d e n a x mat c geometry n wh h ll the theo em f the geometry are de- d ced f m a le ted et of axı ms o po tulates th t e assum d to be t ue The at of th geom try fully det rm ed by the set f tat ments form ng the po tul tes

Let *P* d ot a nempty b tr ct et, who e el m ts de ted by p q and so o re all d p p ıt (f s ggest e es) nd a ppose *P* ı cl sed w th pe t t a ary peratı de- ted by ( ) and a b y op r tıo de oted by th t ıf p q are a y lem nts f *P* then p nd p q m t b un q e leme f *P* An addı t nal b ary ope t d ot d by $\supset$ and ead ımplıe ı defined n *P*

D fi ıtıo If p q are el ments f *P* $p \supset q \equiv_D p \quad q$

An e pressıo form d by l ments f *P* and the op at ns ( ) ıs tr th f ct o f a d nly ıf t c f rm to the followı g ynt ct l r l (1) p q r d so n a e t th fu t (2) f *A* *B* a truth f n t ns th n so e *A* d *A* *B* (3) n eq nce f symb ls de tes ı th func tı n le ıt ı st ted d g t (1) (2) r le t s pl ble by d fi tı by a t th f ct A bel f the l s f truth f tı n t t te the l s *of t tolog*es It ıs a med th t the f ll w g f truth fun t o are ta t l (th th po tul t)

true for all of the connectives By u e of the symbol $\equiv_D$ to mean is defined it follows for example that

$$p \quad q \equiv_D (p \vee q) \qquad p \supset q \equiv_D p \vee q$$
$$p \equiv q \equiv_D [(p \vee q) \vee (q \vee p)]$$

In fact all the connectives can be defined in terms of one binary operation the so called Scheffer stroke function $p \mid q$ which may be read p is false or q is fal e Thus

$$p \equiv_D p \mid p \qquad p \quad q \equiv_D (p \mid q) \mid (p \mid q)$$
$$p \vee q \equiv_D (p \mid p) \mid (q \mid q)$$
$$p \supset q \equiv_D [(p \mid p) \mid (p \mid p)] \mid (q \mid q)$$

The logical connectives the letters p q r and so on that tand for propositions (propositional variables) and the parenthese brackets and braces needed for punctuation are formal concepts A propo itional function i a combination of concepts formal or nonformal involving at least one variable which is not a propo ition but becomes one when all the variables are given specified value Examples are (1) p and q (2) $x + y = 2$ and (3) x is president of the United States Unlike a proposition a propositional function has no truth value On the other hand the statement For every integer x $x + 1 = 0$ is a proposition (not a propositional function) even though it contains a (bound) variable A formal function is a propositional function that contains only formal con epts (for example $[(p \vee q) \quad r] \supset s$) The form of a given proposition is the formal function obtained from it by substituting formal concepts for all nonformal ones Thus p q is the form of the proposition Leonard is happy and the moon is blue Notice that in formalizing the above propo ition different propo itions were replaced by different propositional variables A truth function i a propo itional function in which only propositional variables occur and such that the truth value of each proposition obtained from the function by substituting pecific propo itions for the variables depends only on the truth alues of those propositions Examples are (1) $(p \quad q) \vee r'$ (2) Napoleon was a great general and p (where p is a propo itional variable) On the other hand Jones stated that p is not a truth function

This article is concerned principally with the cla s of formal truth functions (that is those containing only formal concepts) and with an important subclass called tautologies [that is tho e formal truth functions such that every proposition obtained from them by substituting specific values (propositions) for the variables they contain has the truth value T (true)] A truth function is contingent provided it a sumes both truth values T and F (false)—here only the classical two valued (Aristotelian logic) truth functions are considered —and self inconsistent provided it has only the value F The character of a truth function is determined when it is shown to be self inconsistent contingent or a tautology

Character of a truth function A truth function may be analyzed by means of a truth table or matrix Such tables are made first for the elementary truth functions p $p \vee q$ p q $p \supset q$ as follows

(I)

p	p
T	F
F	T

(II)

p	q	$p \vee q$
T	T	T
T	F	T
F	T	T
F	F	F

(III)

p	q	p q
T	T	T
T	F	F
F	T	F
F	F	F

(IV)

p	q	$p \supset q$
T	T	T
T	F	F
F	T	T
F	F	T

In every table each row of the la t column gives that truth value of the function whi h is determined by tho e truth values (assigned to the variables) that are entered in the preceding columns of that row For example the second row of table (IV) states that the truth function $p \supset q$ has value F (that is is false) when p has value T (that is is true) and q has value F Since all logical connectives u ed in the logi of propositions are expre sible in terms of negation and disjunction only tables (I) and (II) are really e ential but tables (III) and (IV) are convenient when analyzing complicated truth functions Although the character of any truth function may be determined by con tructing its truth table the method is tedious when the function contains a large number of variable since the truth table of a truth function of n variables has 2 rows A an example the character of the truth function $(p \supset q) \supset (q \supset p)$ may be determined U ing tables (I) and (IV) the truth table of the function is found to be

p	q	p	q	$p \supset q$	$q \supset p$	$(p \supset q) \supset (q \supset p)$
T	T	F	F	T	T	T
T	F	F	T	F	F	T
F	T	T	F	T	T	T
F	F	T	T	T	T	T

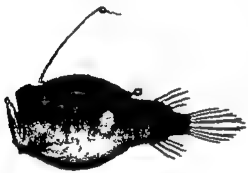
Since every entry in the last column is T the function $(p \supset q) \supset (q \supset p)$ is seen to be a tautology It may also be observed that in each row the entries in columns 5 and 6 are the ame that is for any given values of p and q the functions $p \supset q$ and $q \supset p$ assume the same truth value Hence $(q \supset p) \supset (p \supset q)$ and the two functions are logically equivalent The principle embodied in this equivalence (the law of contraposition) is often used in mathematic

Another device for a certaining the character of a truth function is the method of negation It ometimes happens that the character of the function obtained by negating a given function can be easily

birds the legs, being set far back, are useful for swimming b t m ke the b rds quite clumsy on land. They p e fish underwater w mming with the feet only Loons are Holarctic in d stribution all four pecies oc in North Amer ca three of them in the United States. Loo s are beautiful in teresting birds, b t they are be t known for their call, h h h s been de cr bed as a weird sort of la ght r See GA IIFORMES [J D.B.]

Lophuformes

The anglerfi hes a d the relati es Th s highly modified der f a t nopterygian fishe also kn as the Ped lati was derived from perci form stock t least a early in Eocene time The first d sal fin red ced to few flexible rays, of hich the fir t is pla ed on top of the head and bears t rminal bulb or tassel and fu ctions as a fi h g lu e The ep otic are large and me t behi d the s p occipital Th re are o ribs or epipleurals a d the gill openi g s mall and placed far b ck. Pelv fins, if p ese t, are th acic and the pectoral girdle is n t bly mod fied



Anglerfish Crypt pso l gth t 4 ft (Aft G B G d d T H B O Ichthy l gy U S Nath Muse m Sp B II 2 1895)

There a 3 s b rde s 15 f mili s, 50 g ner and bo t 160 kn wn pe ies All e m r e M t pecies inhabit deep or tr p c l h w ters the l tte f rms re omm ly sedent y n habit Luminescent gans m y be p e e t d me deep-s a pec es th male a e dw fed nd t tached as ect p ra t s n the females See Ac TI OPTERYGII. [R M B]

Bibliog phy E. B rt l n Th Ce ati d Fish Ont ge y T x nomy Distributio d B l gy Dana R pt. 39 1951

Lophophore

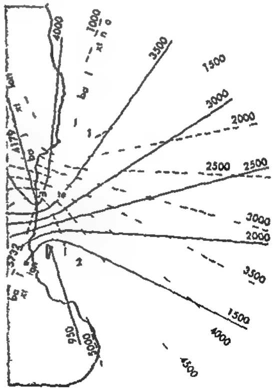
A f ld (kin bear g cil ated t ntacl s It urs in Bry zoa (E t pr ta and E t p o t) Bra hio poda, nd Ph d It s c ular t h s sh e h ped. I some gr p it nc cles only the m uth in th t gr p both mouth d s It i fl bl nd is p ded w th muscl ti su nd n rv tru ks. I the E t procta t can o t act l ke a phin t th s t cl whil n th Ect p octa both t and the tentacles ca be retracted into the body ca ity Tentacle number in bryozoans with a circular loph phore seems less variable than in bryozoans with a hor eshoe- haped lophophore The lophophore serves as a tr ugh for the food beari g stream [M D RO]

Loran

A navig ti n system fr m wh ch hyperbolic lines of positi n are determin d by mea ring the d f fere ce in time of arrival f pul es from widely paced syn hron zed tran mitti g stat on Th in tersection of two such lines of positi n gives a nav gati nal fix or locat n Loran is used by com merc al and mil tary ships and aircraft The name is deri ed fr m LOng RAnge Na gati n

Developed during World War II to pro ide ac urate na igat onal inf rmat on o er a wide area Lo an s nighttime service co erag was 63 000 000 squa e mile nd ts dayt me cove age about 15 000 000 quare miles by Augu t, 1945

Standard loran Standard l ran transmitters send out t ains f p lses about 50 micr econds wide at a r currence rate at or nea 25 pul es per eco d (pps) A seco d ba c rate is 33⅓ pps The h k pow r f a tran m tter is 100 kilowatt. o m re. altho gh the a er ge power is on derably le s. Rad fr quencies employed are in the rder of 2 megacycles



Fg 1 Tw l f p t ge t d by ma te d l t t p o d a fi F f th n g t Da h d l e a g e t d by m t d l o 1 l d l by m t d l o 2 Th fo d g t th l p t d l y t m m ds.

P1 $(p \vee p) \supset p$
P2 $q \supset (p \vee q)$
P3 $(p \vee q) \supset (q \vee p)$
P4 $(q \supset r) \supset [(p \vee q) \supset (p \vee r)]$

These *simple tautologies* were selected by Alfred North Whitehead and Bertrand Russell in *their monumental work Principia Mathematica* as the basic set from which all tautologies can be derived They had an additional postulate

P5 $[p \vee (q \vee r)] \supset [q \vee (p \vee r)]$

that was later shown by Paul Bernays to be deducible from the first four postulates and hence may be deleted as a postulate It is interesting to note that none of the three Aristotelian principles (the laws of identity contradiction and *excluded middle*) are in this basic set They are all deduced as theorems

Before any theorems can be deduced there must be available rules that allow one to go from one step in a proof to another Among such rules are those of formal substitution according to which (1) any truth function may be substituted for any of the variables occurring in a postulate or theorem provided the substitution is carried out completely and (2) any expression may be replaced by one definitionally identical Among the rules of formal assertion are (1) the *principle of inference (that is if P and $P \supset Q$ are postulates or proved theorems then Q is a theorem) and (2) the principle* of adjunction (that is if P Q are postulates or theorems then P Q is a theorem)

It *was proved by E L Post that postulates* P1–P4 are consistent that is it is impossible to deduce from them truth *functions X and X He also proved that the four postulates form an independent set that is no one of the postulates can* be deduced from the others

Non Aristotelian logics In these logics the principle *of the excluded middle (that is each proposition* is either true or false) is not valid There are then at least three truth values possible for a proposition and for this reason such logics are known as many valued In a many valued logic the *reductio ad absurdum* procedure that is so frequently used in mathematics is much less effective than it is in the two valued classical logic for if it has been shown that a given proposition is not false one may not conclude (as is permissible in Aristotelian logic) that the proposition is true The Aristotelian tautology (p) = p is not a tautology in a logic with at least three truth values Doubts that the classical logic is an appropriate one to use in mathematics stem from the modern view that the concepts and relationships dealt with in mathematics have no real existence in the external world It would seem to follow that the a priori nature of true and false then disappears and with it the law of excluded middle! If "true" be interpreted in mathematics to mean provable and a proposition be called false provided its negation is provable then the law of excluded middle is demonstrably false since it has been shown that *mathematics* contains propositions *p* such that *neither p nor* its negation *p* is provable The intuitionistic school of the Dutch mathematician L E J Brouwer rejects the excluded middle law and it forms no part of the logic of that *school* formulated by A Heyting *See* BOOLEAN ALGEBRA GEOMETRY EUCLIDEAN MATHEMATICAL NOTATION CONTEMPORARY MATHEMATICS SCIENCE SCIENTIFIC METHODS [L M BL]

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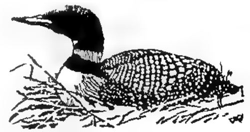
Longitude, astronomical

Longitude determined by astronomical observations as distinguished from geographic longitude which is that shown on a map Astronomical longitudes are determined by the definition that the longitude from Greenwich is identical with the difference between Greenwich mean time and local mean time Greenwich mean time is ascertained by the reception of radio time signals Local mean time is determined by observing either meridian transits of celestial objects or their altitudes near the prime vertical In either case the angle between the line of sight and the direction of gravity is measured the direction of gravity being established with the aid of a spirit level a liquid surface or observation of the horizon corrected for the elevation of the observer The direction of gravity is however not in general precisely toward the axis of rotation of Earth as it would be if Earth were concentrically homogeneous The deviations are called deflections of the vertical they commonly amount to some seconds of arc occasionally reach a minute of arc and vary from place to place A map constructed exclusively from astronomical observations would in consequence be distorted by amounts varying from a few hundred feet to more than a mile See GEODESY [C M C]

Loon

Any of four species of aquatic birds of the genus *Gavia* comprising the family Gaviidae and the order Gaviiformes Loons are rather large diving

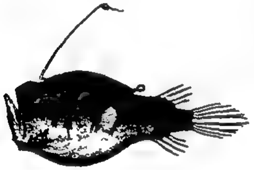


Loon Gavia immer; length 32 in (E L Palmer Fieldbook of Natural History McGraw Hill 1949)

birds the l gs, being set far back, are useful for *imming* but make the bird qu te clumsy on land. They purs e fi h nderw ter swimm ng w th the feet o ly Loo s a e H larct c n di tr bution all four pecies occur i North Ameri a three of them in the U ted St te Loons are be ut ful, in teresting birds, but they are best kn wn f r their ll, hi h has been des ribed a a weird sort of la ghter S GAVIIFORMES. [J D B.]

Lophiiformes

The anglerfi hes and their relati es This h ghly mod fied der of ctin pt rygian fish s also known ▪ the Pedi lat w s deri ed from perci f rm tock t le t early s Eocene time The first d al fin ▪ reduced to a few flexible rays of hi h the first is placed on top f the head and bears t rminal bulb or t s el and f ct ns as a fishing l e The ep tic are larg and meet beh nd the p oc pital There re no ribs o ep pleurals d the gill pe ing small and pl ced far back. Pelvic fi s, if p ent re th ac c, and the pecto al girdle s ot bly modifi d.



Angl rfish *Crypt ▪* ; l gth t 4 ft (Aft G & Good d T H B O I hthy l gy U.S N tl. M se m Sp B ll 2 1895)

There are 3 ub d rs 15 f milie 50 g a and bo t 160 k wn pec es All a e m ne. M t pecies inh b t d p e trop c l h e w t the latt form ar comm ly ed t ry in h b t Lum n sc t rg m y b p t a d n me deep-se spec s the male a dw rfed d t t hed as e topar tes th fem les. S Ac TI. OPTERYGII.

[R.M B]

B bliog phy E. Bertel e *Th C ati id F h s Ont ge y Tax nomy Distributio and Biol gy* Dan Rept. 39 1951

Lophophore

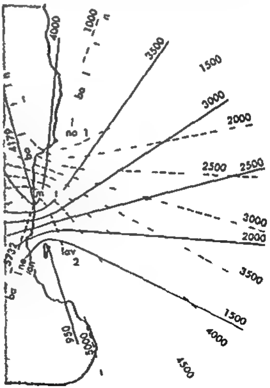
A f ld f k b g c li ted te tacles It oc r in Bry zo (Ect p octa d E t p ct) B h o- pod d Pho d a. It circular t h esh e- shaped. I some gr ps ▪ cir les only the m th in ther gr ps, both m uth d a It fi lle and p d d w th m scl t ssue and n rve tr ks. I the E top octa ▪ ca t a t l k *ch* t o th te t les whil n the Ectop oct both it and the tentacle can be retra ted int the body ca ity Tentacle number in bryozo ns with a c rcular lophopho ▪ eems less variable than in *bryozoans with a h rseshoe-shaped* lophophore. The l phopho e serve as a trough for the food beari g stream [M D RO]

Loran

A na igati n sy tem from which hyperbolic li ▪ f position a e d termined by measur ng the dif ference in time f rri al f pulses fr m widely spaced ynchro ized tran mitting station The in ters ti n f two such lines of po tion ▪ es a na ig tio al fix r l cat on Loran i us d by com merc al d mil tary sh ps and ircraft The name derived fr m LOng RAnge Nav gation

De eloped during World War II t pr ide ac urate n ig tio al nformat n er a wide rea Loran s ▪ ghttime servi ▪ co erage was 63 000 000 quare m le and its dayt me co erage abo ▪ 15 000 000 square miles by August 1945

Standard loran Standard l ran tran mitters end o t t ins f pulses about 50 mic o ec ds wide at a recurren rate at r ne r 25 p lse per e ond (pps) A econd ba c rat ▪ 33⅓ pp The peak power of a t n m tter i 100 kilow ▪ or m e ltho gh the a erage powe is c iderably less Rad o f equen ▪ employed are in the o d r of 2 megacy les



Fg 1 Tw l f po t g t d by m st d l t t p d fi F f th g t Do h d l g t d by m t d l l d l by m f d l 2 Th f d g t th l p t d loy t m m se d

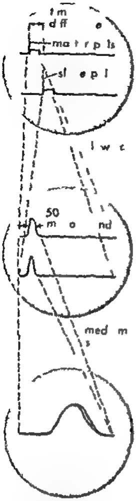


Fig 2 Pulses adjusted to sit on pedestals are electronically magnified and leading edges matched Exact time delay is shown by markers or counter settings

One station of a pair is designated a master and normally sends an uninterrupted series of pulses The second station located some 200–300 nautical miles away is called a slave and must maintain its radio frequency and pulse recurrence rate exactly in accord with those of the master In addition the slave must maintain a fixed time difference (usually 1000 microseconds) between its reception of the master signal and its transmission of the slave pulse If either the master or slave operator notice a change in these relationships the operator periodically interrupts (blinks) his signal until proper adjustments have been made The blinking signal warns navigators of possible error

Because two pairs of loran signals are necessary to obtain a navigational fix at the intersection of two lines of position it is economical to operate a loran chain in groups of three stations (triplet) The center station of a triplet acts as the master for the other two and transmits at two pulse recurrence rates for example 25 and 25⅙ pps

The loran receiving equipment used by the navigator comprises a fixed tuned receiver and an indicator that includes a cathode ray oscilloscope A 100 kilocycle crystal clock with good short term stability is the basis of sweep generating and divider circuits The crystal circuit can be tuned over a narrow frequency range sufficient to adjust to small changes at the transmitter or receiver A multicontact switch in the divider circuits provides synchronism of the sweep circuits to each of the pulse rates assigned the various stations of a chain By this means a number of transmitting stations can operate on the same radio frequency The individual pairs of stations are identified by their pulse modulation The stations are identified as master or slave by causing the master pulse to arrive before the slave pulse The unique time delay between arrival of master and slave pulses at the navigator s equipment is the desired position information

In use the master pulse appearing as a vertical line and identified by arriving first is set upon a pedestal on the upper trace of a slow sweep oscilloscope pattern A movable pedestal on the lower trace is placed beneath the slave pulse Because of their different recurrence rate all other pulses received appear to move relative to the desired pair

A fast sweep shows the form of the pulses The pedestal control permits superposition of the leading edges of the pulses Time markers generated by the crystal clock and the dividers show the time delay accurate to within a microsecond between master and slave pulses This delay is shown on the corresponding line of position on a chart or map

A similar observation on the other pair of signals of the triplet provides a second delay time also shown as a numbered line on the chart The time required for such an observation is generally less than 3 minutes In aircraft navigation it is customary to take a second reading on the first pair of stations and to average the two for greater accuracy because of the distance traveled while taking the readings

Some loran indicators are direct reading that is numbered dials or counters show the delay automatically after the pulses have been superimposed

The distance at which reliable loran fixes are generally obtained is about 800 nautical miles over water from the pair of transmitting stations during

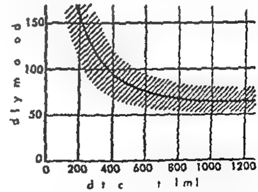
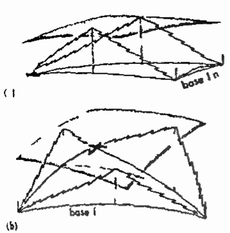


Fig 3 Sky wave delay as a function of distance shows amount that sky wave lags behind ground wave Shaded area shows limits of variation (From J A Pierce A A McKenzie and R H Woodward Loran McGraw Hill 1948)



Fg 4 Sky-w fi h s. ( ) A mpl y d t w d ghtim se (b) T t d b l s l n From J A P e A A McK d R H W d- rd Lo M G w-H ll 1948)

daytme and abo t 1500 miles at night. Daytime d tance o r l nd ı 100–̣50 m les. A cur cy aries o e the rv ce ar a b t g n r lly better th n th t fr m elestial fix The m nimum err r f tand d lo an abo t 500 ft. At dı ta e f 1000 miles fix cc ate t within 10 m le should be poss ble.

Th gr te ghttım co erage s due t the remarkable tab lıty at n ght f the E l y of the ı phe e. Th ı some lo f ccu a y sın e p lses flected f om th on phe e a d layed l u to gr u d wa es a d thı delay n t every h r th same. Th ky w e del y dec eases as th d tanc f tr n mı n ıncea e bec m g ne ly c n.tant t 1000 mıl or m e S RADIO-W VE PROPAGATION

Ss loran. Th ky w e-syn h n zed adapt t on f l an as dev l ped fo the RAF n n ght a d over Germany ı the fi al x m nth f th E ropean phase f W ld Wa II The a age rr f fi ın 22,000 sort was report d le th n 2 miles.

In this y tem yn h zat b twe n m ster and l e t t n s ffe t d u ng E laye flec tions r th th n grou d wa e s g l The l ng b e l es p de an re ı g met l a ur cy th t mp n ates f oth r o s f e ro Var atı n ph e height e ult n an av e ge err of bout 8 μ ec f a gle re d A mınım m rr f 0 9 na t al m l ıs th s tablish d h n the g tor s loc t d t th ı te sectı n of t b lı es ng t ght ngle

D ıng ı o pheri t rms la g arı tions th effec e height f the E l ye m y ause ma m m er s f fi f 5–6 mıl but th occu n t mo than 1% f th time S u f t ry n ghtt m yn hr zat n b m ta ed abo t 99 8% f the tı e, ex ept e poı t of fl ct n a e f lected by al ph om S IO OSPHERE

Lf loran. I tal p r m tal t at of th s lo f q y (lf) v rı t of th l n t h que wa begun ın 1945 using a frequency of 180 k locy les (kc) Further experiment ha e been car ıed out at r near 100 kc

Beca se l ng r pul es (about 300 mı rosec nd) are requ red for lf l r n the read ng error even at sh rt d tances ı likely to be four times greater th n for tanda d loran (about 4 mı roseconds) Spectrum ec nomy a d the d fficultıes of rad ating hort pul s at 100 kc n ce ar ly make the timing ccuracy less

The use of low radio frequ ncies permits l ng b lı e (2 3 tıme the ba e l ne for standard lora) to be u ed and therefore ıncreases th geom trı al acc r cy of the y tem Average l ne-of po ıt n r r f r a sy tem empl yı g a 600-m le ba e line r ed between plus minus 3 mile du ng s mmer day or nıght at dı tan of 500 m le t pl s or m nus 6 miles *(d y) and plus or* mı u 16 miles (n ght) at a d sta ce f 000 nau tıcal miles It has been est mated that the sy tem might have an a erage error f one-q arter of a m le ın the best area

An mp rt nt fe t re po s bl n lf l r n ıs cy l mat h ng whereby the phase of ındı idual ra dio-frequency cycles of a p r f pulses ıs c m p red to p oduce a high accu acy f fix Test of the exp r m ntal v tem g e an erag fine f p ıtıo rror f 160 ft on st tı ns ı50 m les dıst nt.

An nh ent ad ntage ın lf lor n ıs the ange po sible r land where a d stance of 1000 m le day r n ght. an be attaı ed Th s d ta ce ıs om p ble t the a g r wat r

Var u hype boli na gatı sy tems re known a Lo an A r st nda d lo an Loran B or med um dı ta e precı on l r n a d Lo an C r Cyta

Lo a ha the me ad ant ge as any syst m whı h r qu es no transm f d o-f q ency ene gy from th na g tı r ft. Becau e *no c m* mu c t n ı eeded with the avıg to th system d s not s tu at nd ny numbe of veh cles can t.

The c mputat s equ ed fo p oduc ng h rts and t bles ru to m ny m n ho b t nce they be n made the c t pread o er man ob rvations the eby ed c g labor t me, and ex pe e p r n gat o l fix [A A M]

B bl g phy J S Hall *Rad A dı t Nat g tı* 1947 J A Pie ce, A. A M Kenzie, a d H H Woodw rd *Lo* 1948 P C. S drett *Fl ct on A gation F g eerı g* 1958

Lorentz transformations

Th family of mathematic l t nsf rmat used n the pe l theory f el t ty to r late th pa d time a ables f u if mly m ng (n t al) r fer nc y tem Th y we d sc *red* part by H A Lo ent d ıı g hı tud f matte m g m an el t m g tı field d were f rmu lat d mo e compl tely by H Po a d by Al be t E n t n H S d S tw rtıal ef nc f m w th pa e-tım oord t s (x y ,t) and

(x', y', z', t') respectively the equations connecting these variables have the form ($x^0 = ct$, $x^1 = x$, $x^2 = y$, $x^3 = z$)

$$x'^{\alpha} = \sum_{\beta=0}^{3} L_{\beta}^{\alpha} (x^{\beta} - a^{\beta}) \qquad (\alpha = 0, 1, 2, 3)$$

where a^0, a^1, a^2, a^3 are arbitrary real constants. Forming the two real matrices

$$L = \begin{bmatrix} L_0^0 & L_1^0 & L_2^0 & L_3^0 \\ L_0^1 & L_1^1 & L_2^1 & L_3^1 \\ L_0^2 & L_1^2 & L_2^2 & L_3^2 \\ L_0^3 & L_1^3 & L_2^3 & L_3^3 \end{bmatrix}$$

$$\eta = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$$

the matrix L is subject to the condition

$$L^{-1} = \eta L_t \eta$$

where L^{-1} and L_t are the inverse and transposed matrices of L.

The Lorentz transformation group is composed of four classes of transformations which can be organized as indicated in the following table, depending on the algebraic signs of the pivotal element L_0^0 of the matrix L and the determinant of L, which is designated by $D(L)$. Positive signs are indicated by + and negative signs by − in the table.

Classes of Lorentz transformations

	L	$D(L)$
Proper	+	+
Improper	+	−
	−	+
	−	−

The improper Lorentz transformations involve changes of sign (reflections) of the space coordinates, the time coordinate, or both. For additional discussion of improper Lorentz transformations see SPACE-TIME.

The proper Lorentz transformations form a 10-parameter group which can be generated from translations of the space-time coordinates, rotations of the space reference frame, and transformations to uniformly moving systems. See RELATIVITY. [E L HI]

Bibliography: R. Brauer and H. Weyl, *Am. J. Math.*, 57 425, 1935; F. D. Murnaghan, *The Theory of Group Representations*, 1938.

Loschmidt's number

The number of molecules in 1 ml of a perfect gas at 1 atm pressure and 0°C. It is found by dividing the Avogadro number by the normal molar volume or normal gram molecular volume in milliliters. Its value is $(2.68709 \pm 0.00009) \times 10^{19}$/per ml. See AVOGADRO NUMBER; MOLAR VOLUME. [T C W]

Loudness

The psychological property of sound characterized by strength or weakness. It varies most directly with the physical intensity of sound, increasing as intensity is increased and decreasing as intensity is decreased. Loudness also varies with frequency of sound waves. Tones of very low and very high frequencies require much more intensity than those

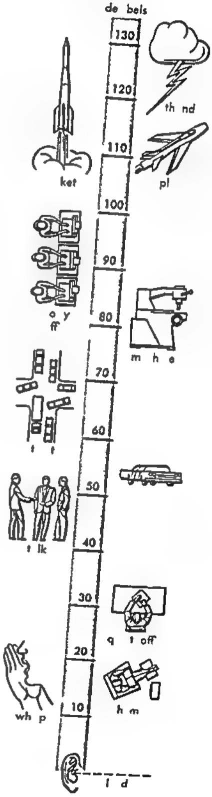


Fig 1 A decibel scale showing relative intensities of common sounds

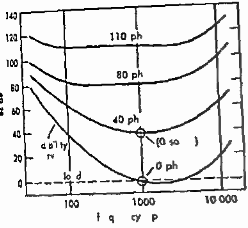


Fig 2 Th d fi t l t h p b tw l d s w l pho d m ty l l d b ls.

in the middle a ge f 1000–5000 ycl per c ond (cps) in o der t be pe m ed qually lo d

Lo dness measur m t is sign ficant i all te h nical and theo etic l m s rem nt of h a ng pe- cially in se n e t gat on and co t ol nal s f ommunic ti n tr m tat on nd n sy t m the study of the me m by wh ch the ditory mechani m resol e d fferen e n sou d nte ty

Decibel In pr ct cal work deali g w th sound the tre gth l sou d i u ally pre ed in decibel (db) unit of phy cal i tens ty o s u d p es e level. D b l ar relat e unt exp ess- g a ti betwee gi en n nd nt n ty nd a ref ce so d A b l s the l g rithm to the b e 10 l the ati f a s u d f g en nt n ity t the r f ten ity a d c bel i n e-te th f a bel 0 en ent n f re e so nd whi h w dely used as a tanda d fo a d ibel scale s the und pres.ure f a t ne f 1000 (0 0002 dy es/ m) h h j t b rely he rd by the m l ear Th s l is somet mes c ll d ero lo dn A ound 10 times as t e n e e gy has a al e f 10 db o e 100 t m s as i t n 20 db Th int ty level l som o dnary n d s h wn n F g l Ve y l d th de t 120 db wo ld be 1 000 000 000 000 times as nten s a bar ly p ept bl sou d l 1000 ps.

Phon Dec b ls are s ful u its f phy l n ten. ty b t d not sp fy th psy h l gi l l d nes f sound A c l f l ud e lev l h d n t s ty les L u es a un t alled th phon The lo dnes lev l f ton s the i t t le l of the 1000 p t to wh h t so d qual loud e s Thu a 1000 ps tone m 40 db h a lo d e f 40 phon Oth frequ es wh h r j dged equ l n lo d ess lso ha l dn le el f 40 phons alth gh th nte ty le el may b o ide bly h gh r tha 40 db F gu e 2 h w the l tionsh p bet een decib l d ph s t rm f ses al qu l l d c t The l w t c n p e nt the ab l te th e h ld a l d ess les l f 0 ph n It h ld be n t d th t eq l l d ess t u s at p g e. ly h gh l ud es l l bec me m e d m e fl tte ed ut I other w ds the h gher the inten ty the more clo ely d es lo d e level corre p nd with inten sity l el through ut the range of frequencies

Sones Phons are ba ed on psychological judg ments f equal l udne but do n t co t t te a true lo d e s cale That i sound of 80 phons i not nece arily twi e as lo d as a nd of 40 ph ns To btain a lo d e s c le ba ed n equal psy h l gical i t rvals b erver were a ked to ad j st ounds to be twice a loud " or half a loud a referen e sound or to be midway between two refer ce so ds. S ch a scale ha b en e tabl hed f r un ts called on One sone i defined s the l udne f a 1000 cps t ne at 40 db (Fig) If both loudne. and ten ity are r pre ented l ga thmic lly l udne s increa es ery rapidly at l w inten iti less and le rap dly at high r inten tie

The l dne s of c mplex ound ar es w th the distribution of their components alo g the fre- quency ange If the c mpone ts a e ffici tly separ ted the loudne s of the t tal c mpl x nd i equal to the sum of the loudnesses f the c m pon nts p e ented eparately If the comp nents are not widely sep ated the t tal lo dne i le than the s m of the omp ent lo dne es Th i app rently d e to the f t that r gio s of cochlear o neu al a t ty et p by the component o e lap wh n th y are cl t geth r *See* AUDIOMETRY DEAFNESS HEARING [K U S]

Bibl ogr phy I J H r h *The M s reme t of Heari g* 1952

Loudspeaker

A dev e th t ns rts ele tric l gn l ene gy into a o tic l e e gy wh ch t r d tes nt a bounded pa e uch as r m r i to outd r p e Th e e t al ha cter tic f the ign l energy m t be p e rved n the ergy c n i n p oces The sh rter term sp k i u ed when it w ll n t be co fu d w th a speak ng per n The term u it in horn n t i ppl ed t de ces c mpri g a m tor nd d ph agm b t lack ng the a u tic le m nt u h a a h r to mplete the sp aker The t rm p k r y tem i orm lly r rved f a pl r l ty f peake t nd the ociated ac o- so es, h rns cabi ts and le t c l etw k re- q r d fo an nt gr ted yst m

Requirements for speech and music Th two m t mp rt nt r ble i a und wa a e pres u e a d the f equ cy f the p s u e lter ti ons he a s the ud t ry r p e of th li tener is mo t cl ely r lated t the a bl s. Th pprox mat d t ry l mit f the ea ar hown n F g l The l m t n rmo s a ge freq n es d ffering by a fa tor of 10³ pres r d ffe ng by a to f 10 nd i ten t s (powe) d ffering by a f t f 10 Fortu ately unds wh h a e mmonly r p odu d h a m d peech e the m re l m ted r g s l h w n F g l The d f r ep od i g e n the ang s is further m d fi d by p ycho c t c fa to s and o S HEARING

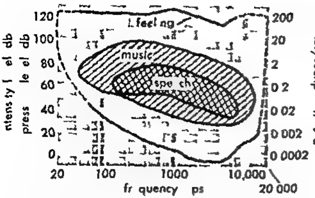


Fig 1 Approximate auditory limits of the ear Shaded areas indicate the intensity and pressure levels found in speech and music Standard reference levels are 10^{-6} watt/cm² intensity (plane wave) and 0.0002 dyne/cm² pressure

Tests have shown that frequency ranges of 80–11 000 cps for music and 150–8000 cps for speech if uniform throughout the listening area give high quality reproduction in an otherwise distortionless system The pressure range requirements are set primarily by listener preference The listener is seldom interested in hearing a wanted sound in the presence of a competing unwanted sound (by definition noise) of the same pressure Noise therefore commonly limits the minimum pressure of interest particularly in music reproduction

Alternatively the requirements of the speaker may be considered from the viewpoint of the complete system designer who normally desires a speaker which does not noticeably narrow the frequency bandwidth lower the signal to noise ratio or increase the distortion of the system Probably the most important requirement is that the speaker not introduce noises that are clearly spurious and unrelated to the signal such as rattles and buzzes Some physical performance characteristics can be adequately measured and specified others cannot however and a thorough listening test is an essential part of any speaker testing program The final judge of the value and adequacy of the speaker (and system) is the ear of the ultimate user See PSYCHOACOUSTICS SOUND REPRODUCTION SYSTEMS ELECTRICAL

Physical performance characteristics Because of the importance of pressure and frequency in hearing the loudspeaker output in terms of these variables is also important

Pressure response Measured at a specified frequency the pressure response is the sound pressure in dynes/cm² at a designated location with respect to the speaker per volt input The pressure is commonly measured under actual or simulated outdoor free field conditions in the absence of unintended reflecting surfaces

Pressure response–frequency characteristic Commonly called simply the frequency response this is the pressure response obtained as the test signal frequency is varied slowly over the audible frequency range (20–20 000 cps) The response characteristic should be free of abrupt changes which are accompanied by transient and sometimes nonlinear distortion A smooth curve also simplifies electrical equalization or compensation

Directional characteristics These are determined by measuring the pressure response at a sufficient number of points in the intended listening region and at a sufficient number of frequencies to predict the frequency response at any listener's position with the desired precision The most common practice is to obtain frequency response characteristics at a few points equidistant from the speaker but subtending different angles with the principal axis of the speaker On axis curves are usually published because the pressure is normally a maximum particularly at high frequencies where focusing is marked In typical environments the response characteristic at 30° is much more useful for predicting the average response throughout the listening region In use the speaker is positioned and oriented to give the most favorable average pressure response–frequency characteristic in the listening region See SOUND

Distortion Although distortion may be more broadly defined loudspeaker distortion is commonly limited to nonlinear transient and frequency modulation distortion

Nonlinear distortion arises from lack of proportionality between the electrical input and acoustical output signal with a sustained (steady state) input signal With a sinusoidal input integral multiples of the fundamental frequency or harmonics are generated If two or more sinusoidal signals are applied the nonlinearity gives rise to interaction between the two or intermodulation distortion resulting in the generation of harmonics and the sum and difference frequencies of the fundamentals and harmonics

Transient distortion arises from the inability of the speaker to follow instantaneously irregular changes in the wave shape of the electrical signal Sharp peaks and valleys in the pressure frequency response curve are to be avoided because they indicate the presence of inadequately damped resonances which give rise to this distortion These poorly damped resonances color the reproduction and when present at high frequencies they are detected as a ringing sound

Frequency modulation of a signal is the alteration or modulation of its apparent frequency by a second or modulating signal It occurs when the radiating diaphragm is vibrated toward and away from the listener by the modulating signal The velocity component with respect to the listener produces a Doppler shift See DOPPLER EFFECT

Electrical speaker impedance This is the complex ratio of the applied sinusoidal voltage across the signal terminals to the resulting current The normal or loaded impedance Z_s the free or unloaded impedance Z_f and the blocked impedance Z_b correspond respectively to operation with the

ormal aco tic lo d in a acuum and with the ot nd d phragm blocked r mmob lized F / t The f r fa t r M of the motor 1) the c mplex r ti f the f ce equired to lock r imm b li e th mot r to tl e g al mp t current to the m to nd (2) the c mplex ratio of he res lting p n r t oltage to the el city f th mechan al sy tem I a mo ing c l speaker the fi t q atity q ls Bl wh B is th e age c d l fl x d ty thr gh the c nductor nd l is th du t r length The nd q a tity eq ls Bl. Wh o tent t ar sed the quant ties h th me magn t de b t oppo te ign nd cat g a t ecipro al latio h p th t is M $-M$

The ormal mped c f a peake s

$$Z_V = Z_b + \frac{M^2}{Z_m} \qquad (1)$$

h Z the t tal effecti e m han l m pedan of th m g y tem in l ding di phr gm and a l d I a m ng-c il peake M^2 B^2l In t o- lectr de lectr tat c p ker M $-(E/d)$ wh e E_0 i th dc b as lt ge, d_0 the er g bi ed l ct de p r t o and ? tum f q e y Th ec nd t rm n the ght hand de f Eq (1) ar e fr m m ti n of the m g y tem d ll d the l aded r no alm t al mped e

Effic ncy Th peak r effi ency i the at of th seful t c e gy utput to the le t ic l ga le e gy i p t The y tem a ail ble p w ff e y the t of the f l ac u t en gy tp t t th e gy the g l sy tem will supply t de g at d i t n e.

Th ac u t c tp t may b obt i d by det mining th t ty (see b l w) f th sou d wa a n mber f q id t t po t f m the pe ker nd f e field (tdoo) ond ti n and mm g t l gr ting th te ty n all d r t n The d a h uld be se e l tume the m x mum d men n f th pe k nd a ffi i t n mb of po t m t be ed t p rm t c ur te i terp la t and t g t Becau e sou d inte ty me ter are ra ly l bl the pre re me su ed l d th bo t t c dit n b t ot i ormal l i ing room th t ty I the d t o of p p g t

$$I \quad p^2/\rho c = 2.42 \times 10^{-} p \text{ watt/ m} \qquad (2)$$

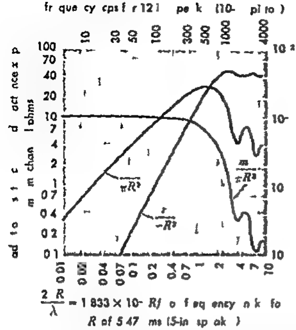
b r p the p e re in dy e/cm ρc th har ct tic mp d e (h r t e) f a r ρ th d ty f dry 0 0012 g/ml a d c the loc ty f p p t n f th so d w n 34,290 m sec both t 20 C d 60 mm Hg p e re Th l t ic l p t p we the m p t rrent squar d tim s the t e p rt f th lectr l rm l mp d n *Se* S UND I TE TY SOU D PRE SURE

Speak pow at g (i put) Unl therw ated, th th m mum utp t p w t g f its inte ded a c ated mplifier when the ign l s spee h and m sic a d the ampl fier is op ated n it l near (ndi torted) rated regi n U der the e n nditio s the a erage p er o 15 ec i tervals will b 1–2% and tl maxim m pow r t any e freq ncy er a ? ec interval will be 10–15% of the r ted lue As an e ample 10-w tt peaker is i tended to w rk with a normally ope ated 10-watt mplifi r with pee h and m ic input It is not expected to perate c ntinu u ly w th 10 watt input at all frequ ncie in it t ans m tted f eque cy b d w thout di t rtion or fail ure

Speaker types Speakers ar comm nly cla si fied by terms wh ch d cribe the r three mporta t f nctio l p ts the m t r d aph agm and acous tic r di t on ontr lling element The mot r co n ele trical energy into m han c l nergy a d n ple the elect cal s gnal so ce omm nly a amplifier to the d aphr gm C mm m t r type a e m i g co duct (p in pally m i g co l dy ami r ely ribb n cond ctor) a d ele tro tat M i g c du t peakers are th e in which the mech nic l f ces re ult f m magnet c ea ti n between th field of the ur ent n a m ng nd t r and a te dy mag eti fi ld In a mo ing l peake the nd ct is n the form f a il ond ct ely o e t d t a ou ce f l ctri al ergy nd me h n ally att ched to th d a phr gm An el t tatic peaker is ne in which the m ch ni l d pl ceme t are prod c d by th eti of elect t t fi ld Other m t r type wh ch n lud th m g ti armat re p r mati p ezo lect i and n c type e di u sed in the efer nc l ted i th bibliography

Th diaphragm is the eleme t whi h ca s s th ai t ib at a d i b ted by th m t h n e t c pl the r lo d (rad t n imped n e) t the moto

The adiat n tr ll g eleme ts r st u t r gid n n b t g n mally n n b rbi g t u t r whi h trol the d rg nce of the ou d w e fr m ne or b th de f the di phr gm d pre nt o c tr l m ract on betw en the fr nd ba l d at n Th p c p l fun t n i to c a the o d pre e n the li ten g eg both by i cr a i g th en gy co er *effic n y* d by d r ct ng the m tt d wa e the d ed d t V brat n of the d phragm pr d c light lt r t n i c e se a d decrea e th i p r b and bel w tm phe c pre re In e occ r n n d s d c e oc th th At l w f eq n s the f nt n w c n e h the b ck f th di ph gm (d th b k p ess wa e c r a h the fr t f th d aphr m) b f e the d aph agm h m d pp ably He Im t c mpl te p u e eu t al zat o d t u t r t f r nce, oc s un l s igid s f baffl nte p ed n x t n i n f th di ph agm upp t Th term baffle lly ppli d t el t ly flat tr tur f b ta t l a a In dd t n baffles, th r m



Fg 2 Average adiation resistance reactance and mass per square centimeter of a flat r gid p ston vi b ating n an nfin te rigid nonabsorb ng baffle Piston rad ates into a sol d angle $\Omega = 2\pi$ steradians (hemi sphere) λ = length of radiated wave cm (F om K Henn y ed Rad o Eng neer g Ha db k 5th ed McGraw H ll 1959)

mon radiation controlling tructures are conven tional cabinets (open back boxes) total enclo sures (closed boxes) vented or reflex enclosures (boxes closed except for one or more openings through which the rear radiation is modified and combined with the front radiation to augment the output over a narrow low frequency range) and horns Speakers are al o frequently clas ified as horn and hornless (direct radiator) type A direct radiator peaker is one in which the diaphragm radiates directly into the listening region rather than through a horn It nece sarily employs ome other type of radiation controlling structure such as those listed above

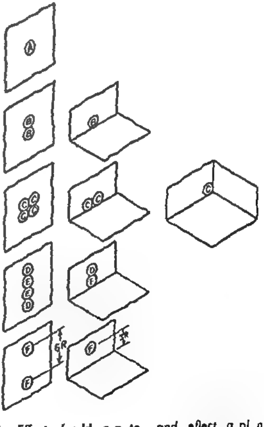
Radiation impedance The added impedance to motion of a diaphragm or ound radiating surface arising from its contact with air is called the radia tion impedance Radiation re istance is the com ponent arising from energy radiation and radia tion reactance is the reactive component A major problem to the speaker designer and one of im portance to the u er is that of obtaining efficient energy transfer or coupling from a relatively high motor and diaphragm mechanical impedance to a low air radiation impedance

The average radiation impedance per unit area of a flat pi ton is hown in Fig 2 When the length of the radiated wave λ exceeds the perimeter of the diaphragm (when $\lambda > 2\pi R$ at low frequencies) the radiation reactance is mass reactance and pro portional to frequency and the radiation resistance per unit area is proportional to the frequency squared and to the area The acoustic power P radiated by a piston is

$$P = r v^2 \times 10^{-7} \text{ watt} \qquad (3)$$

where r is the total radiation re istance (obtained by multiplying the per unit area value from Fig 2 by the area) and v the rms piston velocity cm/sec

If two or more identical speakers are mounted close together in a common plane and supplied with signal energy from the same ource the com bined diaphragms will have substantially the ame radiation impedance at low frequencies as a single diaphragm of the ombined area Differences occur as the wavelength diminishes (as frequency in es) and approaches half the diaphragm perimeter By mounting a speaker adjacent to one or two large rigid nonab orbing surfaces such as a floor or floor wall combination the radiation resi tance may be made that of one speaker of a two or four peaker combination as shown in Fig 3 Each surface by complete wave reflection adds an image (by analogy with an optical mirror) which the diaphragm cannot distinguish from a true peaker or pair of speakers (see IMAGE ACOUSTICAL) An alternate way of con idering this effect is to note that the solid angle into which the speaker radiates is π $\pi/2$ and $\pi/4$ steradians or half quarter or eighth spheres respectively A further advantage of locating a speaker in the corner is the narrower angle over which uniform high frequency re pon e is required



Fg 3 Effect of add g p to and eflect g pl n on ad ati n mped nce All p t s m rked w th the ame l tter see the same ad t on imp dance (F om K Hen ey ed Rad o Engi ng H dbook 5th d M Graw H ll 1959)

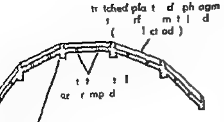


Fig. 4. S pl fied ct o al v w f a two-el c trode l ct t f p ke f th typ ed t obt pp t ly cyl d c l wa e fro t at h gh f e quencies. (F m K H ey d Rad E g r g H db ok 5th d McG w H ll 1959)

Direct radiator speakers *These re the most* d ly u ed p k rs Of the e bsta tially all f the general pu p se and pec l p rpo e low fre quency *(woofer)* peakers a e *of the* m *ing-coil* type. Electr tat c p ake s are sometimes u d a high frequ ncy peaker (t eeter) n b ad band y t m and nf equ tly as g ner l purp se peak

Mov g-c il sp ak s W d ly ed be u e th y an co e a bro d f eq e cy ra g (5–8 ta es) these pe kers are omp ct rel bl a d low n co t. Their ailable po e r syst m effi en y is lo t p cally 0.5–4%

Th ir lati ly un *form* effic en y p t 1000 cps r m is att ed by pla *ing the fu d mental me*hanical re onant frequen y near the lowest fre quen y of int rest This s th f equ ncy at wh h th d ph gm *and* air mas s e es nated by the d phr gm s p n ion a d a tiffn s if pr ent At f eque ie that a e h ghe than thi by a f ct r f from 2 (1 octa e) to 10 r s the n rm l im pedan e i sub ta t ally th blocked impeda ce h h a a m g l peaker is la gely re t A constant olt g and o tant ternal e st n gnal sou ll g e a fai ly nifo m cu t nd hen f rc in this range Thu the d ph agm e locity s es in rsely w th f equ n y d th r di ted p s ind pe dent f f eque cy

El t o tat c p k In the e p ake the me chanical f es re p od ed by the ct o f le trostat fi ld St ct rally they p it r i h b e lectrode s f e t m d rn d hragm. Th m abl lectr de i comm nly thin pl t heet w th a c nd ct e fa e whi h m y be a met ll *fo l or* p ted film Tw fi ed lectr des, one n e h s d of the m bl lectrode, are u ed n pu h pull types when th dia h gm ampl *tude* m y be r l t ely la g A gl fixed lect ode is u d n i gle-e d d type (see Fig 4) The re mm ly ed s h gh f eq ncy p ak or tweet r A high d b p tential, f the o d f k l olt appl ed be t een the fixed d m ble elect od s to n e sen itivity *and r duce d tort on Th ac potent* l is uperimpo ed on the dc resulting in an altern t i g force on the diaph gm Some ad antages of the electro tati peaker are (1) the diaphragm can be very l ght (2) the for e is di tribut d er the d aphragm (3) the transient and phase di tor t on m y be kept l w by proper de ign and (4) the cost may be low Some of the disad antages are *(1) the permi ible diaphragm amplitude* i n mally l w leading to large area d aph agms r limiting the lower cut ff frequency (2) the norm l mp dance is *substantially that* f *a capac tor and* i diffic lt t mat h pr perly e cept n lim ted freque cy ra ge and (3) becau e of the h gh po tentials d electric pr blems are in ol ed *See* ELECTROSTATICS

Radiation controlling structures These struc ture wh ch control the di erg nce of the sound wav and the interaction between front and back *radiati n are primarily f the h rn or h rnl s en* clos re types.

Enclos es These are rad ati n c ntr lli g truc tures of the hornless type. E closures may be cl ss fied as t tal in which the rear rad ti n i om pletely absorbed by the clo ed rear e cl sur nd ented r r flex in which the re r rad at on is hifted in ph e mod fied in amplitude, and com bined w th the f ont radiati n to incr ase the tot l r diat on n a freque cy ba d of appr ximately an oct e j st bo e the lowest tran mitted frequ n y *At still l wer freq e ies the total ad at on i sub*tant ally red c d by pres ure ne tr lization or de tru ti e i terference

T t l ncl su es are used pr mar ly when the lume is smaller tha d ir ble for a refl x type. Be u the r tiff e l mits the m nimum d a phragm–moto system tiffn s the mass mu t be r i ed to reduce the r nant f eque y In the e fle type h gh r ffi en y bta n d n the lowe t octa e by us ng l rge c b n with les a r t ff ness nd mak ng u e f the eflex o r ar ac t c n tw rk ph h ft a d rad at n A *mpl fied* ket h of a efl x enclo ur i hown i Fig 5 The bi et a r st ff ss o pl s the diaphragm to th i m s n th nt port, reg o

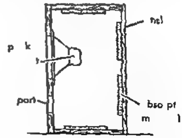


Fig 5 O typ f fl e l wh h p rt l g d pl d d ph gm t bt m m m d f m th p rt d t Ph h ft f b ks d r d t n bt d by h f l l m d p rt m s. (F m K H y d R d E g g H db k 5th d M G w H ll 1959)

Horns Structurally a horn is a rigid nonabsorbing tapered duct or passage It may be straight bent or folded with concentric sound passages The small end to which the horn unit (speaker) is attached is called the throat and the large radiating end is called the mouth

Functionally it is (1) a tapered acoustical transmission line used to match the relatively high impedance looking back into the diaphragm to the relatively low radiation impedance seen at the mouth and (2) a device which by virtue of its mouth size and shape controls the directional properties

V Salmon has discovered a family of horns with interesting properties to which many common horns belong In these Salmon or hyperbolic exponential horns the cross sectional area A is related to the axial distance by

$$A = A_t\left[\cosh\left(\frac{x}{x_0}\right) + T\sinh\left(\frac{x}{x_0}\right)\right]^2 \qquad (4)$$

where A_t is the throat area x_0 is a constant fixing the axial scale of length T is a constant determining a member of the general family and the cosh and sinh are the hyperbolic exponential cosine and sine functions respectively The longitudinal sections of these horns for various values of T are shown in Fig 6 for straight axis circular horn

The performance of a horn depends principally on the throat impedance and its dependence on frequency Although waves reflected from the mouth introduce variations with frequency into the throat impedance it has been found that the average impedance is close to that of a horn with no reflected wave The throat impedance in mechanical ohms of catenoidal horns with rigid nonabsorbent walls and negligible reflected waves is given by

$$\begin{aligned} Z_t &= R_t + jx_t \\ &= A_t\rho c\,\frac{[1-(f_c/f)^2]^{1/2} - j(Tf_c/f)}{1-(1-T^2)(f_c/f)^2} \end{aligned} \qquad (5)$$

where ρ c and T have been defined previously f is the frequency and f_c is the cutoff frequency given by $f_c = c/2\pi x_0$ Thus the reference axial length x_0

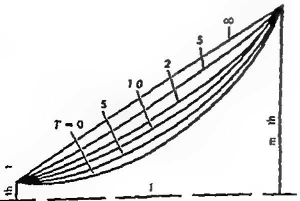


Fig 6 Longitudinal section of straight axis circular cross-sectional horns of hyperbolic exponential or catenoidal family (From K Henney ed Radio Engineering Handbook 5th ed McGraw Hill 1959)

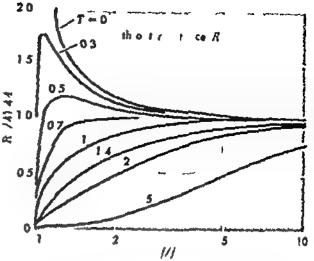


Fig 7 Frequency dependence of throat resistance for horns of various values of T Below f_c the resistance is zero The factor 41 4 is the value of ρc in cgs units at room temperature (From K Henney ed Radio Engineering Handbook 5th ed McGraw Hill 1959)

is of fundamental importance in determining the behavior of the impedance In Fig 7 the behavior of R_t for various values of T is shown

Speaker systems Two or more identical speakers may be used to improve the low frequency efficiency and increase the permissible input and output powers or by proper relative orientation improve the directional properties More commonly the two or more units cover complementary frequency range The more important advantages are (1) improved frequency response because each type of unit covers a moderate range (2) higher system efficiency for the same reason (3) improved directivity characteristic because the diaphragm (or horn mouth) for the highest frequency range may be made relatively small (4) improved transient response because many of the artifices used to obtain extended frequency ranges in single units make the transient response worse particularly at high frequencies (5) reduced intermodulation because large amplitudes are confined to speakers reproducing low frequencies and (6) reduced frequency modulation

Coaxial units comprise two or less commonly three speaker units mounted on substantially the same axis in an integrated mechanical assembly Appropriate wave filters or dividing networks control the amplitude and phase of the electrical signal reaching each unit The term coaxial speaker should be reserved for a coaxial unit with its required acoustic radiation controlling structure

Speaker placement In single channel or monophonic systems speaker placement is largely controlled by the desirability of uniform response in the listening area A corner location in a room is desirable to improve the low frequency efficiency and to reduce the angle the high frequency radiation must cover In stereophonic systems multiple speakers and signal channels are used to reproduce

ke patial effects p ent th gin l ou d n me t. In the e peaker pla ement is m re ritical and th reg on for ati factory r prod c i is rel ti ely lim ted The impler con enti al tem employ two han l and two pe ker or e ker t m. These peak rs e l ted m etri ally th m prefe bly l ng the h rter ll l t p al m ll li te ing r m the speake 6-10 ft ap rt. Pr perly o ne ted identical pe k s ill gi d ti l pre re a d pha e al g the pla e of ymmetry betw en the peak r hi h eides th med an ertic l plan f the room. Optim m l tener l t ons in the plane f ymm t y d ghly greate than th peak r epar ti n by a f to of 1.5–.S Tr er e l a t ns are l m ted by th need fo h ing the m re em te pe ke les than ft farthe f m the li t t p eve t the preceden e eff t in wh h th ler ignal t k s b t nt l contr l f the ar f t arr l p ecedes the l tte by approxi at ly 5-35 milli d rr p d ng t p th le gth d ff e f 5 6-39 ft F add t l ma t al n peake placeme t s ARCHITECTURAL COL TICS. [H S K]

B bliog phy L. L. Beran k, *Acoustics* 1954 K. H (d) *R dio E n g H dbook* th ed 19 9 F V H t *El ct acoust Th f aly is f T du t d lt H t l B ck g and* 19 4 H F Olson *A ust c l E g e n g* od ed., 19 7 V S lm *J Ac ust S c Am* I (3) 199-218 1946

Louping ill

A l d se f heep cap ble of prod en tral ner y tem m fe t t s. It h fi m the B t h I le I fect s h bee ported alth gh rar ly m g pe s worki g w th heep

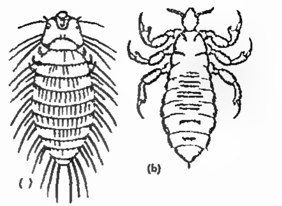
In h ep the d a e i u ally b ph w th a aemic i fi nzal ke ph f ll wed by ph l se l m th fi t pha e lly th ex te t f lnes

Th s m mber f th ll stan ti k b ple of the gr p B b i Ch a t t s, d gn s. d epid m ology m l to those f the ruse f th e mple S A IM L IMTS ARBOR VIRAL ENCEPH LITIDES [J L.M]

B bli g phy T M R ers a d F L. H fall J (d) f *al d R ck tt l Inf t ns f M* 3d d 19 9

Louse

A y f r m s. i gl p t c i e t be- lo g g i the d Mall ph d A pl The M ll ph h g l d t gu hed by h g m thpart fl tte d bod e and b d h ds. The y g es mble the d lts They lly l m t d t gle h i p lated h t Th d t met m call d th b d l bi g b d l e h t l p es lso t r k m mm l N k w t p t m



( ) Ch k l se *M p g ll* l gth 0 1–0 04 (b) H m h d l *P d l h m* l gth t 0 1 (F *m E L P lm F ldb k f Nat l H st y* M G w-H ll 1949)

t be di e se t rs Se al tt k d me tic imal t bl p ultry Abo t 2 00 pe e a e k wn *S e A* OPLURA MALLOPHAGA

Th biting l fe d up f th ha p de mal cale d dried bl od n the urface of the h t They d t k blood M y cti e w ft n e s They are tra mitted f m ho t to ho t b body c nta t Ab t 40 cies 7 f whi h mmon p a t ze po ltry Lice cau e p or h lth ultry th gh th rr t tio d h y nfe tat on m kill y g b rds

M ll phaga are e d ly t lled by l ndane pray u ed l mb t w th DDT Th mbination i effecti fo a wide r g of p lt y p t

The Anopl k g l re ch ra te zed b p g k ng mouthpart d n rr w u lly p t d h d Th An pl a are also mall a d d pre ed d the y g esemble the d lt Like tl Mall ph ga they a e bl g t ry p r tes d ll p nd th t life n th same h t nim l Th A pl k bl d The e ar bout 300 p te m t f wh h m o p fic th r h st elat ons A number f them p a t e d m t c animal l d g al sp c es cat tl d m h es d g a d h p Two mp rt t p t f m

P d lus h ma us the h ad d body l e of m n w ll k wn s the te It ppear wh r th l g d tions f m n a e d ty a d wded It th ctor f typh S TYPHUS F VER, EPIDEMIC (LOUSE BOR F) The nim l as- m d ff t form i th he d d b dy ac s b t th y ll the ame The gg all d n ts hat h b t a w k nd ly 3 w ks eq ed t mpl te th l fe y le It w effec t ly c ntr lled d g W ld W ll by the e f DDT p wd Th ab l e f m *Phth bus* lly fi d t the p b c a d p r nal gi s f t h t C t ry t w d ly h ld p th imal t ll el t ly mm It t kn wn t b th t f ny d e d as- ly k ll d by DDT p wd [J D B]

Lovebird

A name applied to several small parrots or parakeets kept in captivity They are native either of Africa or South America The green lovebirds are American Lovebirds have short beaks and long

The lovebird *Melopsittacus undulatus* length to 8 in (*From E L Palmer Fieldbook of Natural History McGraw Hill 1949*)

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Low level counting

The measurement of very small amounts of radioactivity The instruments used are special modifications of standard radioactivity measurement equipment designed to yield greater detection efficiencies and lower background counting rates than those necessary for ordinary applications These techniques are applied mainly to the measurement of long lived natural radioactive isotopes and their daughter products cosmic ray produced isotopes and isotopes produced artificially during nuclear explosions

Because of the statistical error associated with the measurement of radioactivity accurate assays of samples with small amounts of radioactivity cannot be made in the presence of large amounts of radiation from other sources This can be readily seen from the relationship between the sample count rate A its percentage error E the background count rate A_b and the length of time the sample is counted t

$$E \cong \sqrt{\frac{A_b}{tA^2}} \times 100$$

For example the percentage error for an overnight measurement of a sample with an activity of 1 count/min in the presence of a background of 90 counts/min is 30% This error can be decreased by reducing the background or by increasing the sample count rate Doubling the sample count rate is twice as effective as halving the background Thus most low level counters are designed (1) to hold as large a sample as it is practical to obtain and to prepare (2) to record with as high an efficiency as possible the radiations from the sample (3) to have as low a background counting rate as possible The instruments which have been most widely used are internal gas counters solid source β counters and scintillation counters For a general discussion of various types of particle counters and a listing of related articles *see* PARTICLE DETECTOR

For internal gas counters the sample itself is used as the filling gas for a discharge tube such as an ionization chamber proportional counter or Geiger counter Because of the high detection efficiency of such chambers they are ideal for measuring the radiations from α and weak β emitting isotopes The counters are designed to hold the available sample in a minimum volume Where large quantities of sample are available counters as large as 10 liters have been used with gas pressures up to 5 atmospheres

For α counting the background can be largely eliminated by selecting only the most energetic pulses produced in the counter For weak β detection however it is usually impossible to separate the sample pulses from those caused by β particles emitted from the materials making up the counter by γ rays entering the counter from the outside and by neutrons and mesons produced by cosmic ray activity

Gamma ray background The greater part of the γ ray background can be eliminated by placing the counter in an iron or lead shield Because of its purity mercury is sometimes used as an inner shield to remove γ radiation originating from impurities in the iron or lead Even with an 8 in iron shield and a 2 in inner mercury shield a small γ ray component remains Since these residual radiations result mainly from the reaction of cosmic rays which have penetrated the shielding their contribution to the background may change with time This is because the cosmic ray flux at a given point on the earth s surface varies slightly with solar activity and with atmospheric pressure the former affecting the amount of magnetic shielding required and the latter the amount of physical shielding This time variation introduces a significant uncertainty into the background counting rate in applications involving very small amounts of radiation such as carbon 14 dating beyond 30 000 years

Two methods for eliminating this background have been devised One is to use additional physical shielding to absorb the cosmic rays H DeVries found that by adding 30 in of iron over the counter and by placing a 6-in neutron absorber such as paraffin plus boric acid between the iron

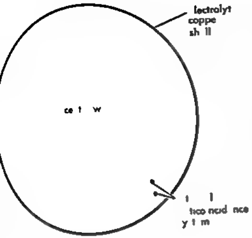


Fig. 1 C ss sect f p p rt l g t th i t l t d y t m Th l ge d t rep w t 0 01 d m t w d th thod f th nd d l i l t d th m ll dot th 0 001-n. d m t w wh h f m th d f th w co t Th α d β d t o g t g at ll f th t w ll l ct t ted by γ-ray st 'k g th w ll rd d by th n- mal syst m d y p d g p l th entral t l t lly ll d

and th inne me ry h eld t fold red t o in the i ble mp t can be bt d Th other m thod is t tru t a s t f a t co de e ters thin th g cou t t elf Th may be d with nes f wir as hown i Fg 1

Sin e t mode at p res the majo ty f the ec ded γ ray a d tect d d to th f ct that el ct s a j ted f m the nt lls, rejecti n f p lses urring sim lt ne u ly a e f th t es ar the wall a d th c t t l min t m h f the γ r y c mp t f the ba kgr d W e t t f the f ct th t part f this γ y c mp e t ne with time th l s of ampl o ts that re lt f m t d ing th ring f uld utwe gh th tivity gain b ght bout by the r d ct n b kgro nd

Beta part cle background Th l minated by hoos g co te m teri l with l w di t ty Steel, pper d pl t cs f t e, h e on d bly l r ad t ty tha b l minum r gl s. Th t l t de e y t m d f γ) s effe t n r m g any d l β ad t n.

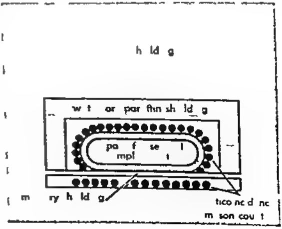
Neutrons and mesons The e p rt le a n t effect ely m ed by n lead hi ld g A ffin h ld ll rem the n t d the inter al t d y t m w ll em the meso s. Whe i ternal y tem d, t of G g r t an be pl ed d th sample ter n h a m th t any m so t g the sampl te ll p th gh at l t e Geig te Co d t p l e r lec tr ic lly c lled A d gr m f typ l l w le el g u ter a d its a oc at d hi ld ng is hown Fg 2.

Gas counters I tern l g s cou ters are used f r the det t n f c m ay prod ced carbon 14 a d tr tium The m ll q ant tie of arg n 37 and krypt n-85 p od ed by nuclear e plo io s can also be measu ed with su h des es Alpha acti ty from rad n and ll ron eman ti from u ani m a d thor m mineral ha b n me u ed i un hi lded gas o nte

Solid source counters Fo str n, β m tters d f r is t pes which a not be p t i to su table gaseous form low le el solid u e c nt rs a e of ten d Th c unters u ually e d wi dow pro- p rti al co te s o Geig r t be but in some as the s mple s m unt d the ins de of cyl der whi h is placed within the c unt r The latter gi a more f so ble sample-to-backgro d rat o Backg u d r d ct n is compli h d in much the am m er s f the ternal g cou ter S nce the c te are mu h m ll r m tal h eld g and a ri g f e ternal a tic cid ce t bes p oduce ffici t b ckg nd du t on A number of the isot pes s ch as str nt m 90 prod ced d ring cle r te ts ha been detected w th uch q p- m t

Scintillation counters Many low le el radio- ti ity meas eme ts are m de w th cintillat co nters The e gy of th radi t ns is erted to l ght wh ch is ecord d by a ph t multipl er tub Th meth d h p e espe ially sef l fo th d t ct on f mall q antit es f w ak β ra diat from amples liquid f rm The sample dis l ed n uitabl liquid ph ph r and pl ed i cell d g ed t ff ct all the light pro- du ed int e m r adj ent ph t m lt pl e tubes S h y tems h e fficienc es s high as 80 per ce t f r th detect n f the weak β particles f m c b n 14 d tritium.

S n e th typ f nter s mo e ensiti e t γ di t n than a d ha ge-type tube m m ph m t be pl ced phy al h ld de s gned t b rb th γ mp t f the nat r l



Fg 2 C ss sect f th sh ld g d f l g l m l l w-l l g co t

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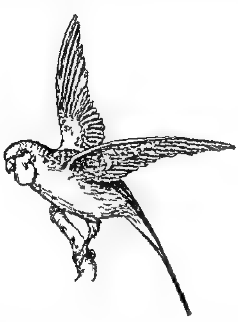

The lovebird *Melopsittacus undulatus*, length to 8 in. (*From E. L. Palmer, Fieldbook of Natural History, McGraw-Hill, 1949*)

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For α counting, the background can be largely eliminated by selecting only the most energetic pulses produced in the counter. For weak β detection, however, it is usually impossible to separate the sample pulses from those caused by β particles emitted from the materials making up the counter, by γ rays entering the counter from the outside, and by neutrons and mesons produced by cosmic-ray activity.

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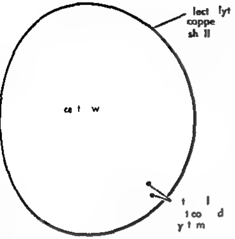

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and the in e me cury hield a tenf ld red ctio in the ariabl omp n t can be bta ed The other method s t n tru t set of ti o den e c unte s w th the ga co te tself Thi m y be d ne with a e e of w es s h wn Fg 1

S e t mode ate g s pr s ure th maj ty f the ec d d γ ay a e detect d d e to the fact that le tr ns m ejected fr m the nter alls, reject l p l occ rr g im lt n lv ne f the re n ar th w ll nd n the ter e l m nate m ch f th γ y comp nt f th ba kground. W r t n t f the f t th t p t of th γ ay c mp ne t r es w th tim the l f ampl unts that lts f m nt d g the ti.g of ures ld tw gh the se t ty g n b ght bo t by the d ct n b ckg o d

Beta particle background Th s lim ted by choo g counte mat l w th low ad o t ty Steel, copper and pl t s f n t e ha e der U'y l w d t ty th n b al m um gl s. Th t rn l m in den sy t m ed f γ ay ffect n em r g ny e d l β ad t n.

Neutrons and mesons The.e pa t l s e n t effecti ly r m ed by le d hi ld g A pa ffi h ld w ll mo e th n t d th ternal tic d ce y tem w ll em e th mesons. Wh t al y t m s ed a s t f Ge g nt n be pl ed a o d the mple t r i h man r th t ny me e t g the sample u te w ll p ss thr gh t l t G g nte Co d t p l e a lec t lly elled A diagr m f a typ l l w

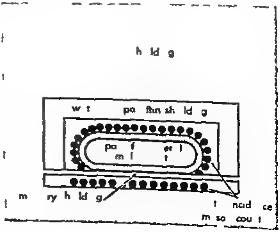
le el gas n te d ts ssociated sh elding s h n in Fig 2

Gas counters Internal gas o nt rs e used f r the dete ti f c m c ray pr d ced c rbon 14 and tr t um The m ll q antities of g n 37 and kryp t n-85 produ ed by nuclear e pl ns can also be m s ed with h de ice Alpha acti ity from r d d thoron ema tions fr m anium a d thori m mi eral ha e b e meas red in un hielded g s counter

Solid source counters For t g β emitte nd f r i otopes wh h ca t be put i t a uitable ga.eo s f rm l w l el l d s ce co t rs are f ten u ed The cou te s are usually e d w dow p o- p tion l c nter r Ge ger t be b t n some the ample is mou t d on the nsid f a cyl i der wh h is pla d with the cou ter The l tte gi es a m re favor ble sample to-backg ou d ratio Ba kg und redu t on i compl hed much the me m ner as f the i t nal g count S nce th c unt r much m ller metal hield g a d a ing f exter l antic de e tubes produce a fficient b kgro d red t on A numbe f th sotope uch s str nt um 90 produc d during n lear t ts ha been d tected with such eq ip- ment

Scintillation counters M ny low l el dio- ti ity mea em t ar mad w th c nt ll ti n nters The e gy of the radiat s c erted i t light which s re d d by ph tom lt plie t be This meth d ha pro e pec ally useful f r the d t tio f mall q ant t es f we k β r d tion f m mpl i l quid f rm The sample d ssol ed n it ble l q d ph ph and pla d in ll d gn d t efle t all the light pro- d ed i t n o m e dja nt ph tom ltiplie t be S y tem ha ffic en s as h gh as 80 ce t fo the d tecti n of the we k β p rticles f m b 14 a d trit m

S e th type f n nt r m re en ti e t y ad t tha d ch ge-typ t be m r em pha m t be plac d n phy l sh eld g d g ed t ab o b th γ mp n t f the atural



Fg 2 Co ct f th sh ld g d f l g l m lt l w-l l g t

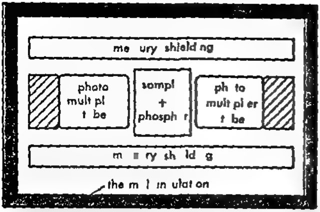


Fig 3 Idealized diagram of a low level liquid scintillation counting system The two photomultiplier tubes are connected so that only pulses occurring simultaneously in both tubes are recorded The mal background is further reduced by cooling the whole apparatus in a refrigeration unit

background In addition to the background originating from nuclear radiations electrical noise pulses in the photomultiplier tubes must be eliminated This has been done by facing two phototubes to the same sample Only pulses seen simultaneously by both tubes are recorded Fast electronic circuits greatly reduce the possibility of accidental coincidences between the noise pulses from the individual tubes Cooling the apparatus in a freezer unit also aids in reducing the noise level A diagram showing the design of a typical low level liquid scintillation counter is shown in Fig 3 This system has been successfully used for the measurement of a number of isotopes including tritium and radiocarbon [W S B]

Low temperature physics

A study of the properties of gross matter at such low temperature that the quantum character of the substance becomes observable Most famous among the effects attributed to the quantum mechanical nature of macroscopic matter are (1) superconductivity (2) superfluid liquid helium (3) magnetic cooling and (4) nuclear orientation The topic of cryogenics includes the method of producing low temperatures In addition to the considerable technology involved in refrigeration there is a very important section of low temperature physics concerned with temperature measurement and related instrumentation

Production of low temperature Low temperatures such as those of liquid hydrogen (normal boiling point 20 4 K) and liquid helium (normal boiling point 4 2 K) are produced from the gas phase by the use of three mechanical devices (1) the gas compressor or pump (2) heat exchangers at several places along the path of flow of the gas and (3) devices for expanding the gas such as a piston expander and a throttle valve These are shown schematically in Fig 1 and the flow of helium gas may be traced from the intake of the compressor past the water cooled heat exchanger and into the liquefier A basic concept to grasp in understanding why the temperature drops when the gas is allowed to expand against the piston is that the process has occurred at constant entropy Entropy S is a thermodynamic property of the system of gaseous molecules and it is useful to think of its physical meaning as being that of the degree of disorder of the system The entropy versus temperature plot in Fig 2 shows for the gas system a series of constant pressure curves The thermodynamic process at the compressor (with water cooling to keep the temperature constant) is shown as the path from point α to the point β The entropy decrease $\Delta S = \Delta Q/T$ where ΔQ is the heat removed at temperature T during this reversible process that is assumed to be ideal The diagram also shows an expansion of the gas against the piston as the path from point β to the point γ This is done at constant entropy so that one may think of the pressure and temperature variables as having shifted suitably to preserve the degree of disorder Energy was removed from the

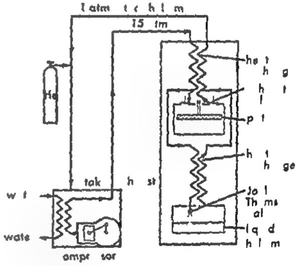


Fig 1 Equipment for producing liquid helium

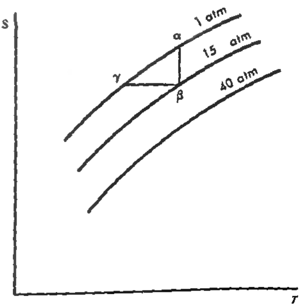


Fig 2 Entropy temperature plot for helium gas

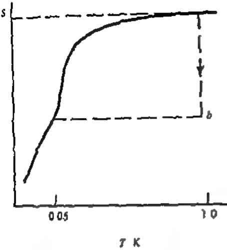


Fig. 3. E t py t mp t e d g m f p t m thro l m.

gas o y tem by the rk t did n the piston Fgur 1 ho s till nother e pans n at the throt tle al Jo le-Th mson l e t wh ch a fu th t mperat e d p a d some l q efa t n may occu The thr ttl l e p n n t nstant nth lpy and is some hat m re subtle To s m up b iefly th rmodynam c ari bles m y be man pulated in tr ghtf rwa d manner t p du a cld temper ture, for ampl by l qu d helium By gorous p mp g the l q id hel um the apor p e sur ay be gre tly redu ed and the t mpe atu e of the l q d bec mes f the rd r l K.

T p oduc temp rature b low 1 K, it s n ces sary to u a sy tem wh h nt s d s rde (e tr py) and t pe te uch a way a t br ng bo t rde a d l w th e tr py S ch a ys tem is th set f electro s with n a pa amagnet salt hose magnet c d p le mom nt may be ori ted po e ful m gnet c fi ld The e tropy tempe at e diagram (F g 3) r pre e t a pa magnet c alt su b p ta ium chrome alum. The p oce i carr d t n two step rep esent d by the p th t b and th n b to c In the first stage, a l rge m g t fi ld i sothe mally ap lied t th salt, nd the heat f m gnet zat n carr ed ff to the urr und ng a liqu d h l m bath t abo t 1 K The the h t ta t f the lt th the bath i r mo ed nd th st p b to the d m gn t zat n au ed by turn g off the ex t rnal magn t fi ld an sd abat e hich the ent opy f the s lt r m s tant Dur g th f t stage the m gn t c e rgy d n ty BH/2 j ul /m nta ed w th the lt h s moved out a d d ip ted eddy curre t heat g n th external m gnet The temp r tu e ha dropped t some 0 04 K a d the b thermody nam c r aso g s m la t the e p n g cool g l a g n F g 2 p th β t y Th de cr ted by th po ful extern l field t 1 K maint i ed by ry e k m t c fi ld w thi th salt beca se of the cry ub tant al dr p n t mper ature. P th b t s a c t nt nt opy p oce n

wh ch the deg e of d order remains c nstant am g the mag tic d p les The lattice vib ations of the salt are al eady n their zer point energy tate a d there mply s not eno gh entropy left to the lattic sy tem to lter the order f the elec tron d pole ystem The latt ce sy tem cannot go to debt w th a negati e entr py beca e uch a thi g is ab u d T sum up by u ng stat tical me han cs the entr py s e p e sed by means of the part ti n function and the Helmholt p tent l A as follow

$$S = -\left(\frac{\partial A}{\partial T}\right)_B \tag{1}$$

wher

$$A = -kT \ln \sum e^{-E/kT} \tag{2}$$

The e e gy lev ls E in the mag et c field B re nteger mult ple of the qua t ty βB where β is the electr n dipole moment f the ab e equation k is the B ltzm nn on tant It can be shown that the factor in the exponential $E/kT = βB/kT$ m st r ma n n t nt f the ent opy is to remain on tant If the l rge val e of B dr ps to the m ll i ternal dip le d pole m gn tic field w thin the alt tself b cau e f the dem gnetizati n p oces then the temperature T must become sm ll n or der t k ep th b e fa tor in the exp ne tial a nstant Th d e not demand th t the dipoles be al gned as in fe omagnet m beca e they can bec me antip allel lig ed a in antiferrom gnet m and st ll m inta n the const nt ntropy re quir me t A di n f th el ctr n sp n y tem a d magnetic c ling nat rally le d to the matter of n cl ar orient ti n nd f rther red ct n t mperature S e CRYOGENICS

Low temperature phenomena Consider a ol d pec men f m tt r (for e ampl a cry tal of LiF be ause the Li nucleus ha a m g et c moment) h i g c lle t on f nucle with magnetic mo ment μ wh h s taken s pa allel to th p n a gul m m nt m ch a te i d by I A cons der ble pol izat n will occ nly f the en rgy μB s l ge comp d t th energy kT becau e the e quantitie ppe r as they d d i Eq (2) fac tor f an p nti l The r quirement is mo t demandi g of e the be t q ipp d l w t mp r tu l b at ry Magneti fields f 10 weber /m mu t b mb ed with t mpe at es f 0 01 K b fo e ign fic nt p la izat n of the n cle will b obtai ed An alternat e pp oach to n l ar pola zation i to btai larger mag eti field t th nucleus by u ng th ntri s c magnet c fi ld f th tom elect o s (f the rde 100 webe /m at u h lo r ng) The i teract n of these fields w th μ gi e r se t hype fi stru t e n pt cal spectra Th t 0 01 K mall ext rn l field of nly 0 01 w be /m n or ent the le tr n p y tem n arly to sat at n f e, d th field a t o th n cle by the spi y t m o larg that ig fica t n l r polar zat appe r An ex m pl f p i magnet alt whose cl ar m ment may be p la ed thi w y e c rta cobalt(II) salts. S e MAG ETOCH MISTRY

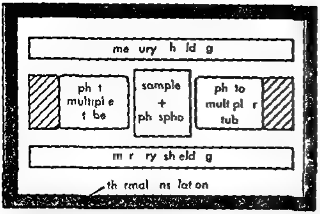


Fig 3 Idealized diagram of a low level liquid scintillation counting system The two photomultiplier tubes are connected so that only pulses occurring simultaneously in both tubes are recorded Thermal background is further reduced by cooling the whole apparatus in a refrigeration unit

background In addition to the background originating from nuclear radiations electrical noise *pulses in the photomultiplier tubes must be eliminated* This has been done by facing two phototubes to the same sample Only pulses seen simultaneously by both tubes are recorded Fast electronic circuits greatly reduce the possibility of accidental coincidences between the noise pulses from the individual tubes Cooling the apparatus in a freezer unit also aids in reducing the noise level A diagram showing the design of a typical low level liquid scintillation counter is shown in Fig 3 This system has been successfully used for the measurement of a number of isotopes including tritium and radiocarbon [W S B]

Low temperature physics

A study of the properties of gross matter at such low temperature that the quantum character of the substance becomes observable Most famous among the effects attributed to the quantum mechanical nature of macroscopic matter are (1) superconductivity (2) superfluid liquid helium (3) magnetic cooling and (4) nuclear orientation The topic of cryogenics includes the method of producing low temperatures In addition to the considerable technology involved in refrigeration there is a very important section of low temperature physics concerned with temperature measurement and related instrumentation

Production of low temperature Low temperatures such as those of liquid hydrogen (normal boiling point 20 4 K) and liquid helium (normal boiling point 4 2 K) are produced from the gas phase by the use of three mechanical devices *(1) the gas compressor* or pump (2) heat exchangers at several places along the path of flow of the gas and (3) devices for expanding the gas such as a piston expander and a throttle valve These are shown schematically in Fig 1 and the flow of helium gas may be traced from the intake of the compressor past the water cooled heat exchanger and into the liquefier A basic concept to grasp in understanding why the temperature drops when the gas is allowed to expand against the piston is that the process has occurred at constant entropy Entropy S is a thermodynamic property of the system of gaseous molecules and it is useful to think of its physical meaning as being that of the degree of disorder of the system The entropy versus temperature plot in Fig 2 shows for the gas system a series of constant pressure curves The thermodynamic process at the compressor (with water cooling to keep the temperature constant) is shown as the path from point α to the point β The entropy decrease $\Delta S = \Delta Q/T$ where ΔQ is the heat removed at temperature T during this reversible process that is assumed to be ideal The diagram also shows an expansion of the gas against the piston as the path from point β to the point γ This is done at constant entropy so that one may think of the pressure and temperature variables as having shifted suitably to preserve the degree of disorder Energy was removed from the

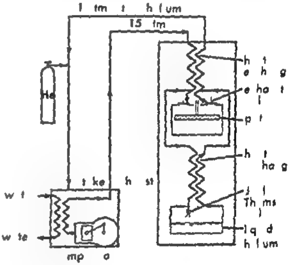


Fig 1 Equipment for producing liquid helium

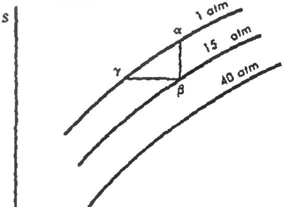
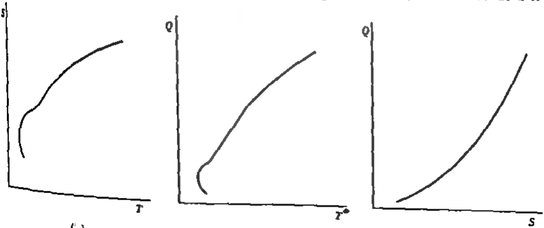


Fig 2 Entropy temperature plot for helium gas

gas er n l sed i a fixed and k own vol me in thermal q libri m ith th t bject wh se t mper ture is to be determ d meas rement of the gas pressure ould b ffic ent for pec fi at on of the temperat e, pr ded the al e of the onstant in the equat o r lating P J nd T were known The al e f thi c n ta t is a e e arbitr ry be se the mber a s gn d t me ely fi es the i e f th d gree. Use of a si gle lu f th qu n tity a ob o s d s de t m howe e and to s- eth th been d c d d by i ternatio al agreement to ss gn t the tr ple po nt of w ter the absol te tempe atu 273 16 K A mea urement of the gas therm m t r p e re at thi relat ely as- ily rep od ed fi ed po nt f t mpe tu e then de fines the t t f r ea h gas therm m ter The f ll ing fundam ntal diffi ulty r ma ns Altho gh certain g ses a e mo e n arly pe fe t than oth ers, an d l gas as ch doe not t F p c tical me urem ts, t i the efo e n ce ary to mod fy the mple p edu o tl ed ab e t correct f the deal hara ter f r l gase In dditi m y the prec tio s m t b taken to e l able result To the ext t th t the m as ur ment h e been a ef lly mad a d p pe ly rrected al d absolute t mpe tu a e obtained hich an be a igned l w temp ratu eference scales or th ppr pri te p mete al es of ta d ard seco d ry thermomet Bel w 1 K h we er th rm meter b me ele s bec e the m x m m p e e at wh h gas th mom te n b per ted m t i d t min mize nid lity correcti s, l ys h pp e i bly l th n th a po pr e f the gas b g sed d at 1 K th po p es re f all g ses ther is l eady or p dly bec m g neglig bl

Adiabatic demagnetization below 1 K S nce the m eme t of t mpe t e bel w 1 K i tr bly l t d to th d t on f th se low t pe tur s, th e t ubjects w ll be j tly d used. The e tial d t n f r the p du ti ll temp at es is l rg e tropy dent in th t m t be cooled An th rmal d tion of the y tem entropy by an ppropr te parameter change follow d by an i entr pi re rsal of the ame paramet r hange to its o ig nal lue always results in a lower ng of th temperatur At temperature f 1 K and below th e tr py cha g s ccompanying any parameter change as o at d with g s uch as the p re bec me negl g ble and n f rther temp rature reduction i p s ble To c nt nue down the tempe at cale a d ffe ent phys cal sy tem equ red pos e ng at the e t mpe at re large amo nts of entr py S ce the nt py of all y t ms de re es w th t mperatur h w er the e a e f w u h s tems a lable In 1933 W F G auque nd P Debye in depende tly s gge ted that p ramag etic lts m ght tisfy the ab e equ reme t on tl e pre mise that the random or entati n of the mag etic m me ts f the paramagnet c atoms in th cry tal w uld c nt bute en at t mperature of the rde of 1 K an appre able mo nt to the tropy f the system If h a y tem is m g eti ed ther mally t 1 K the elem ntary magnets will be al gn d p rallel t th fi ld d rect on and the ys- t m ent py co re po dingly d crea ed If th sys- t m then th rm lly ol ted nd dem g tized it will co l i nt pically to that temp at e wh h w uld it lf h e been ufficient in ero field t ha reduced the entropy by the me mo t s did th th rm l m gn tiz t on Th is the te hnique of l w temp atu e p d tion by ad ab t c demagnet izat o S e CRYOGENICS

In rd r to me re the t mpe at s p od ced by th p o ed a new k nd f th rm m ter is r qu d Aga f tu tely the bsol te temp ra t re f a d l pa m gneti alt relat d imply t a the ily me rable q a tity its u cept b l ty d j t in the c e of g thermometry thi pa meter may be u ed to e t bli h a p o i on l tempe at re ale for u bel w 1 K This lat hip T = co t/χ wher χ i the m gneti ept b l ty of the s lt a d the tant is d te m d t s m k wn high t mp ature established by g th rm metry is k wn as the C ri



( ) (b) ( )

Determina io f th h m dy m t mp t be- low 1 K. ( ) Mea m t f S f ct f T (b) M m t f Q f f T ( ) Sl p f Q-S rv g T

Nuclear orientation becomes particularly interesting if the oriented nuclei are radioactive. Anisotropy of the intensity of α, β, and γ radiation from oriented nuclei has been observed experimentally. These experiments have led to important conclusions in the field of theoretical physics of nuclear interactions. *See* PARITY (QUANTUM MECHANICS).

The properties of matter at low temperatures can be most surprising. There are a large number of metals which become superconductors at low temperatures such that the electric field **E** within the metal is zero. The magnetic field described by the induction vector **B** is also zero within the metal superconductor. Many of these same metals exhibit at low temperatures (and in the normal state) an unusual diamagnetism with a peculiar periodiclike dependence on the applied magnetic field. The effect was first noted by W. De Haas and P. van Alphen and has been extensively studied by D. Shoenberg. Magnetic nuclear resonance studies on a number of systems have been useful in understanding the properties of matter at low temperature. For example, solid hydrogen is normally composed of 75% ortho molecules and 25% para molecules. The ortho molecules have the magnetic spin moments of the two protons aligned parallel, and this

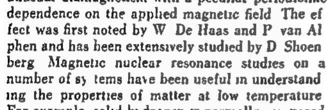


Fig. 4. Apparatus for liquid hydrogen studies.

results in allowed rotational quantum numbers of $J = 1, 3, 5$, and so on. Even in the solid state and even at 1 K the ortho molecules must rotate. By magnetic nuclear resonance studies and by calorimetric studies the detailed way in which the molecule occupies the zero point energy of rotation has been studied. Figure 4 illustrates the apparatus for these studies made on solid hydrogen under pressure. *See* ABSOLUTE ZERO; CRYOGENIC ENGINEERING; ENTROPY; HELIUM; LIQUEFACTION OF GASES; LOW TEMPERATURE THERMOMETRY; REFRIGERATION; STATISTICAL MECHANICS; SUPERCONDUCTIVITY; SUPERFLUIDITY. [C.F.S.]

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Low temperature thermometry

The very low temperatures produced by various cryogenic techniques are measured like any others by thermometers. Because conventional thermometers lose their sensitivity as the temperature is reduced, those used in this temperature region tend to be somewhat unfamiliar. These low temperature thermometers nevertheless meet the two main criteria required of all thermometers: reproducibility and a monotonic variation with temperature (preferably according to some simple law) of the thermometric property being measured. Additional conditions such as high sensitivity and independence of the thermometer readings from magnetic field may also be imposed for special applications. Factors such as these, as well as the degree to which the instrument must satisfy the two basic criteria mentioned above, determine the selection of the thermometer.

For accurate work, low temperature thermometers must be calibrated before each use either at a number of well known fixed and reproducible temperature points or against a suitable standard thermometer. Accurate and relatively simple standard secondary thermometers, which have themselves been calibrated against a primary standard, are readily available. The primary standard serves, as its name implies, chiefly to establish secondary thermometer temperature scales, improve existing ones, and accurately determine useful fixed points of temperature, for example, the triple point of hydrogen.

Low temperature thermometry resolves itself, therefore, into the basic problem of assigning numbers on the absolute temperature scale to achievable and reproducible low temperature states and the choice and the calibration of suitable instruments for the practical measurement of low temperatures.

Temperatures on the absolute scale are defined in terms of the second law of thermodynamics by the equation $T = dQ/dS$. The absolute temperature of any system is therefore given by the limiting value of the reversible heat absorbed by the system per unit change of its entropy. To determine a temperature on the basis of the above definition would be a formidable task, however. Fortunately, it can be shown that valid absolute or thermodynamic temperatures may also be obtained from measurements with a gas thermometer. Although a laborious technique, gas thermometry is ordinarily much simpler than a temperature determination based upon reversible heat and entropy measurements. *See* ENTROPY.

Gas thermometry above 1 K. Gas thermometry is based upon the concept of an ideal gas, for which it may be shown that the pressure times the volume equals a constant times the temperature, or $PV = RT$. Hence, if a definite amount of such a

ow-temperature thermom t ▪ (Cont)

Temperature-mea uring instrum nt	Appl able temperatur nge K	Appr ate precisi n t l w temperat e lim t K	Rem k
Magnetic therm met rs	Fo all tempe a tures below 1 K (h e bee used fo speci l pu poses at h h r temper tures)	D pends upon t mperatu ange n l q uid h h m r g p eci on bout 0 001	Second y tand d diff e t p magn t salt samples may require ı d d al al b t ons salts e unstable and mu t be carefully h n dled to en ure con ta y of l mic l ompo tion useful ne rth less f 01 to 1 K using a cal br t n d te m ned e the theo et cally o e per m tally below 0 1 K the sus ceptibility serves as a th rmom tric pa ameter
El tronic paramagnetic material ▪ hromium m thylamine l m	10 to 1		
N lea paramagn tic materials uch ropper	10^{-4} to 10		

▪ A the case of a g thermometer no id l paramagn t c ex ts ny mo e than do a d l gas, a d th el ▪ t bt n r li bl tempe tu e mea ur m nts f m l to b ut 0 1 K mall c recti s f r d al ty mu t be appl ed At lower tempe t these re t ons be m les and less certain, d e ntually mplet ly r babl T est bli h o ect b l t tempe t r s th s range, it has p o ed ne e ary to tilize the b s thermodynamic d fin t n of temper t re gi en t the beginn ng of th arti le Th d e n the f ll g ay Start ng t n absol te t mpe atur accu t ly k n by g s therm metry f r e m pl T th ▪ ptib l ty of a par m g et c alt s ed n e fi ld nd f m th mea ur me t m Cure l w co t nt s d te m n d Th n mai t g th sy t m t thi t mper tur l t th m g n c fi ld be bit a ly ı r a d to s m al e for ample H The e t py f th lt w ll d er se by n amo t ▪ rately alculable (t these t mp r t) by a athe mpl cated b t no eth) t t ble the r t cal formul As m thi decre e n t py t be ΔS If th pa am g ne c salt is w th rmally l t d and lowly de m gnetized sent p c proc s w ll ▪ arried A d scribed abo e d th tempe atu will f ll The pub lity at thi w l w t mp r t n be m a ed t pr de pr l t m re tur $T = C/x$ N w let a m a r d am nt l h t ΔQ be dded t th solat d pe m n t rt n t t mpe at re to T a me ed by t ptib l y If th pr es pe ted tarti g to f m T d g ng t T and so th a at both f S nd Q ith T n be bt n d T th n be l m ted f om th e l t hip t g S fun ı f Q The l p of thi cu th n y ld th e t bsolut t mpe t r t t ted th h Q and S nd f om thi inf mation, th pr p r ect t th pr al t mpet t r bta ned fr m usc pt bil ty u em t n be made l the ll t t typ ı l c r e obt ned in u h m asu em nts re pre ent d

Low temperature thermometers Low temp tu es ally de ı e f m the pre nce of liq e fied as a dem gn tized p ramagnet c lt ▪ h f whi h c ta s h ilt n t mpe atur mea re m nt c p bility ı th form f ap r pr re nd m gnet c thermomete e pect ely If howe r th low temp at ▪ pr d ced by a ref gerator if use f the thermom ter m nt ned bo ı p o ribed by s me pe ıal equ ı ment, oth r type f thermomete m t be t l ed A ri ty f th e e a lable, th d ffer g p pe tie f whi h en ble n ptimum mat hi g of thermome te t applic t o In th t ble me ample f the mor u es f l low temp ratur the m met s r l ted t gethe w th b ief comme ts n their d a tag d l m tat o S e TEMPERATURE MEASUREMENT [E F H]

Bibli g aphy L C J ck on *L w T mp ratu e Phys cs* 4th d rev 1955 N Kurti *M gn ti m t ery low temp* ▪ and nucl ar ri ntat n *Nu ı m nto* uppl 6(3) 1101 1957 H C W lfe (d) *Temperatu Its M asu ment d Cont ol S enc a d I dust y* 1 1 nd 2, 1941 d 1955

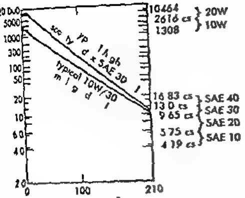
Lubricant

A ga l q d ▪ l d u ed to pr ent c nt ct l pa t n rel ti e m ti n a d thereby r duce f ı ▪ and w ar In m y m ch nes cool ng by the l bri ant ı q lly imp rta t Likewi th l br ant m y be c ll d upo to p v t ru ting d to p e t dep t n of sol ds on lo fitti ▪ pa t

Liq id hydro arbon a th mo t omm ly u d lub a ts b u th y r exp s e a d ly ppl ed d they ▪ good coolant In m ▪ petr l m f a t n r appl cable but f pec al dit o s u h as tr me f temperat re, l t y thet l q ds may be ed At ery h gh

Low temperature thermometers

Temperature-measuring instrument	Applicable temperature range K	Approximate preci ion at low temperature limit K	Remarks
Thermocouples			Simple construction low cost wide range small size ea of installation rapid re po ise no heat introduction at point of measurement careful selection of wires necessary to avoid spurious thermal electromotive force because of inhomogeneities in lead in wires rapid loss of sensitiv ity occurs with decreasing temperature cali brations stable except at lowest temperatures
Copper-constantan	14–350	0 1	Precision at 20 K approximately 0 0 at 90 K 0 01 low temperature calibration may change by 0 5 between coolings
2 1% Cobalt in gold copper	4–70	0 1	Sensitivity at 20 K about 2½ times that of copper-constantan reproducibility of thermoelectric force between different melts about 7% calibration valid so long as thermocouple not heated above amb ent temperature
Resistance thermometers			Normally conducting metals partial supercon ductors and semiconductors have been used all introduce heat at point of measurement
Platinum	4–1100	0 01	Basis of International Temperature Scale to 90 K from 90 to 4 K can be accurately cali brated calibration stable with respect to ther mal cycling if Pt is extremely pure and if wires supported in strain free configuration at 0 K and above sensitivity is of order of 10 ⁴ degrees Pt resistance thermometers rapidly lose sensitivity below this temperature
Leaded phospho bronze	0 03 7	0 001	Sensitivity has been extended to 10 ⁴ degrees measured resistance dependent upon measuring current and upon magnetic field magnetic field dependence can be reduced by addition of bismuth difficult to reproduce same tempera tu e coefficient of resistiv ty in suc es ive wire samples
Carbon	0 0 –20	0 001	Highly sen itive capable of measu ing tempera ture changes of the order of 10 degrees resistance dependent upon measu ing curr nt but essentially independent of m gnetic fi ld
Vapor pressure thermometers	Triple point to critical point of all liquef ed gases	Approx 0 001	Seconda y standard sen itive slow re ding following condit ons must be fulfilled to ensure reliable results uniform liquid temper t e unifor n and known liquid co npo ition (for example orth o-para compos tion in li u d hy drogen) accurate pressure mea urem nt n ple vapor pressure th ermom ters can be constructed which are ugged reliab le d sen itive
Gas thermometers Helium	1–800	0 001	I rimary standard requires extreme care in order to obtain a curate results any whose behavior almost ideal m y be used in g thermometer at low ten per tures th re quirement restricts per ssil le g ses t y drogen and heli m the latter be ng only suitable f use at lo est ter per t r s er de gas thermom ters have be n con t t u g rough l t st rdy pres re dicators t pro d reliab le low tempe t re ind itors f r eng neeri g uses (g s l quef ers)



g. 1 Visc ty t mper t l t h ps fo m lt nd ls.

Iuc sity dex impr ers The fall n v ity th incr a e m temperat re f o l f a gi en grade, i i co ty level can be made les t ep by th len g lighter oils w th polymeric ub tan es ch as polyb t nes and cop lyme s f polym tha ryl tes The polyme may n r a n of b l ty s the temperature cre es and o r ,o dingly the molec les unco l d th cken th base o l more t high than at low tempe atu e nd thus u teract, to some extent the natural de cre e n i o ty the base oil w ld u de g

P ur po nt depr ss nts The dewaxi g pro re oves th h gher melting hydrocarb n but me c mpo e ts till emain which may solidify and g l the o l, nd thus ed ce its fluid ty at l w t m per tures Sm ll amou ts of hemical u h as me tallic soaps, ondensation p duct f hlorinat d ax and alkyl naphthalen s or phenols, polymeth acrylates, and a host of othe s increas flu d ty at l t mper tures The mech ni m f their action still unc rt in, but it probably m ol es ad-orp t n of additi e molecules on th surface f the gr wing ax cry tals The dsorbed lay r th r red es i tercrystal forces or m difie ry tal gr th.

Antioxidants Lubricants are e po ed t x da ti n by atm pheric oxygen in practically all of their appl tions Thi results in format of da d ludges whi h int rfere with the primary f nction of the l bric nt. S b t ntial ncrea s n serv e l fe can be obta ned by u ng small am nts (0.1 10%) of anti da ts Fo l ght m e highly refined o ls s ch as team turb ne o ls hindered ph ols such s d butyl p re ol e ery ecti e. In h avy lubr cants such as e gi ils, amines (phenyl α-naphthylam ne) met l ph ates (x l-earth salts of phe ol d ulfides) nd zin salts of th ph ph tes and carbamate a e i w de d use.

A ti nd f t r d t g ddu es If l d ng f es a be compl tely epa ated by l f m, fricti nd a will be t a min m m Ther m y y t ms, h e er in whi h th ombi a tion f mpo m geom try d pe at g nd two i ch th t a o t o s l film a t be n i tai ed but if no eparating film of any k nd were inte p ed complete se zure would result If th pre ure and t mperatu m between u h con tacting rfaces are moderate the provision of a boundary lubricating film will ffice whereas if as n some gears onditions of both temper ture and pres ure are e re some f rm of extreme p essure (EP) l b cation may be ece ary

The form n wh ch wear m n fests itself in ma chine comp n t aries widely w th the condition from the t trophic weld ng t gether of gear to th urfa es to the l w t n us removal of m t l fr m an eng e cyl der e n within the same mechanical system t may change profoundly with changes n oper t g and n ironmental condi ti ns

In ntern l c mbu ti n engines operating at low cyl nder temperatures for instance condensation of acids from the ga eo s c mbusti n products on the cylind nd r ng urfa es es lts in orro i n wear in uch a es the add tio of alk l ne ea th phenates to the lubricating oil to neutral e the a d ha been ery successful in reducing wear rates

Extr me pre su e additives Certa n types of g ar pa t c l rly the hypoids used in aut moti e re xle t ansmissi n perate u der such e ere ond tion f l ad and sliding peed w th resulting h gh temperat re nd pressu e that ord ry lubri cants ann t pro ide complet p otection ag nst metal contact th le ds to welding, transfer of surfa e m tal and ultimate destruction of the gear Al o in rta n machining operatio s, it is nece s ry to p e ent th ch p from weldi g to the cutt ng tool For s ch pplications lubricants con taining ulfu and chlorine compounds are used At the temp tu es de el ped in the c tact, these ct h mically with the metal rfaces the result ing sulfide nd chlo ide film pro ide penetration esistant low shear stre gth films which pre ent damag t the surfa Care in formul ting the lubric nts must howe er be exer ised to e sure th t rrosion f metal at normal temperature d n t occur Figur 2 shows the damag ng re ults which may occur the absence of s ch p te t e add ti

Dispe sants In i t rnal combu tion e g es om of the p odu ts of comb tion wh ch in lud rbona eous part cle part ally burnt fuel ulf r acids nd wat r enter the oil film on the cyl nd r wall These m ter al m y react to fo m la q ers and l dg s which are deposited on th w rki g p rts f the eng ne. The lubr ant is called

Fig 2 Typ of g f l

temperatures or in places where renewal of liquid lubricants is impossible solid lubricants such as graphite or molybdenum disulfide may be employed

Petroleum lubricants Crude petroleum is an excellent source of lubricants becau ■ a very wide range of suitable liquids varying in molecular weight from 150 to over 1 000 and in viscosity from light machine oils to heavy gear oil can be produced by various refining proces es Studies carried out by the American Petroleum Institute and others have established that crude petroleum fractions consist of saturates (normal iso and *cycloparaffins*) monoaromatics which may contain saturated rings as well as saturated side chains substituted polyaromatics hetero compounds containing sulfur nitrogen and oxygen and a phaltic material made up of *polycondensed aromatics* and hetero compounds Of these the wax free atu rates and monoaromatics are desired in the finished oil in order to obtain the desired viscometric properties and oxidation and thermal tability and so far as po sible the other types of compounds are generally removed Classically only those crudes (so called paraffinic crudes) relatively rich in the desired type of hydrocarbons were used in lubricat*ing oil manufacture* *By atmospheric distillation* neutrals were produced as distillates and the residual fractions were treated with activated clays which removed a phaltic and hetero material to produce bright stock

In modern refining vacuum distillation removes the desired hydrocarbons from the asphaltic constituents (which may be present in amounts up to 40% of the total) and gives oils in the required viscosity and boiling range Extraction of the distilled fractions with solvents such as liquid sulfur dioxide furfural and phenol permits the removal of the polyaromatic and hetero compounds to improve *viscosity temperature characteristics* (*viscosity* index VI) and stability of the oil Dewaxing removes the high melting paraffins

If the viscosity index of the oil is not important for a particular application the most reactive poly aromatics and hetero compounds may be removed by treatment with concentrated sulfuric acid In either case the oil is treated finally with an active clay to remove trace amounts of residual acids and re ins (*heterocyclics*)

Small amounts of heterocyclics such as substituted benzthiophenes quinolines and indoles may remain in the finished oil The sulfur containing compounds erve the useful purpo e of acting as natural antioxidants The nitrogen compounds may be harmful in certain applications because of their propen ity to form deposits on hot surfaces and are generally reduced to low concentrations

The table lists typical *specification data for lubri*cants in everal applications It will be noted that vi cosity is a determining factor in lubricant selection Machines are generally designed to operate on the lowest practicable vi cosity since the lighter fluids give lower friction and better heat transfer rates However if loads or temperatures are high

Viscosity of o ls for var ous applications

Applicati n	V scos ty cent t ke at 5 C (77 F)	Pr ma y f t n
E g ls		
SAE 10W	60–90	Lub at p st n i gs, cyl d rs, al ge be gs cool p t n p e nt d pos t n metal s f ces
SAE 0	90–180	
SAL 30	180– 80	
SAE 40	80–450	
SAE 50	450–800	
Gea o ls		I t m tal co ta t nd w a of sp g rs, hypo d g ars, wo m ■ a s cool gear cases
SAE 80	100–400	
SAE 90	400–1000	
SAE 140	1000– ■	
Avi t on e gin ls	0–700	Sam g n o ls
T que conv rter fl d	80–140	Lub cate tr n m t pow
Hydr ul c b ke flu d	35	Tr n m ■ power
Refrige to il	30– 60	L b icate compresso pump
Steam t ■ e o l	55–300	Lub cate r d t on g a g cool
Steam cyli d r oil	1500–3300	Lub cate in p esence f st m t h gh tempe tu es

more viscous and less volatile lubricants are required Change of viscosity with temperature is often of considerable practical importance and it is customary to express this in terms of vi co ity index an arbitrarily chosen scale on which an oil from a Pennsylvania crude high in saturate and monoaromatic content is assigned a value of 100 and those containing a relatively large amount of cyclohydrocarbons both paraffinic and aromatic (from naphthenic crudes) will be in the 0–50 viscosity index range As already de cribed the refiner can produce oils of high vi cosity index from naphthenic stocks but yields may be low

Multigrade oils In order to standardize on nomenclature for oils of differing viscosity the Society of Automotive Engineers (SAE) has established viscosity ranges for the various SAE designations (see table) By the use of relatively large amounts of additi es for improving viscosity index it is possible to formulate one oil which will fall within the range of more than one SAE vi cosity grade the so called multigrade oil illustrated by Fig 1 Since all viscosity index improvers also increase visco ity it is necessary to u ■ a ba e oil of low iscosity to formulate such oils Since the is cosity increasing effect of the additive decrea es with increase in hear rate an artificially thickened oil of this type behaves as a light oil in engine parts under high shear and thereby friction is low but acts as a heavier oil in low shear region or at higher temperatures However olatility and *ability to protect* high shear parts from rubbing set limits to the use of light oils in the e formulations

Additives for lubricating oils It is often de ir able to add various chemic ls to lul ricating oil to improve their phy ical *properties* r to btain some needed impro ement in p rf rmance

k peed PTFE l d n it elf or on m tal h effi ie t f fr t m the l we t range observed fo bounda y lubricat on (ab t 0 05) The frictı n ri es t alue comm n for other plas t ft r the liding je d p e tic l lue d th h gh fri t n tends t per t when ret n g t l peed

It l k ly that th is the m l effect the i ci d f hı h pr m ted by the extremely l w therm l du ti ty f PTFE d it can be com bated t n derable extent by ing tl e PTFE ın pp m t ıx The e f su h a mat ıx l o educes th ea hich w ld ccur with PTFE al e Th t p of tr tur ı ed s a elf lub t d bear m te l

Greases A l b c t ng gre e a lıd r em f d l br c t mpr g a th kenı g (or gel l g) g nt n l quid l bri ant. Other ingred e t imp rt g pec l p pe tie m y be ı luded An importa t p p rty f a gre e its sol d nat re tha a yı ld l Th en ble grea e t r t ın itself a bearing s embly w tho t the a d f t pe e se ls, t p d ıt o n eal ag n t th ingres f m ı t e and d t, nd t emaı n rts l urf es d ff rd p otect o g t m ı tur o n, espec lly dur h t d wn per od

The g ll g a t u ed n m t gr are fatt ar d soap f l th m d um cal ium a d al mı m, P ta m ba m nd le d s p ar ed oc lly The f tty d employ d a e ol f lm t c, t c, a d ther n b yl id d med f m m l fi h and eget ble o l The f soap n gr e s l m ted by pha e h nges t r melt ng p ts) that oc r ın the r nge 50–200 C Becau e many applicatı s r quir peratı n ab e th s tempe ture grea s ha been ı troduced which are th ck ed by high melting sol d such a lay lic org nic dyes rom tic am de and ea d at e In the e ca e the upper l n it of appl cat n et by the ol t lity or by the xida tio and thermal tabil ty of the ba e il To exte d the pe ting ra ge to xtreme of h gh d l w temp atu e ynth tic o ls m y be u ed as the ub trate Sil on e ters nd flu r carb s ha e ll b en empl yed f r this p rp e As ın the f l qu d l br ant a n dd ti e uch as xida t on nh bit EP a nts and antı u t add ti s e freq ently u ed ın grea es V l til ty f the b e o l ı part cul rly mpo ta t ın g a e be cau e t ıs on tantly po d a thin film n the b ar g u faces

Structure of greases *The gellı g age t ın m t* soap-ba e g ea es s pre n t as crystalline fibers ha g l ngths f l 100 μ and d amet s $\frac{1}{10}$–$\frac{1}{100}$ f th l ngth Th fibe th ck n the o l by form g n tw k br h heap struct e n whi h the l ı held by cap ll ry f c s F a gi en concen t at n f ap the l ge the l ngth to-d ameter tı f the fibe the g eate ı the p ob bil ty f network ju t n f rmat n d the ha de ı the g e H w er not all ap f rm s h y tall ne fibe lum n m ap a n t bl except n The e de e that l min m oap mol ules f m etwork k t th t f med by p lyme m l cule N so p th ck ners a e pre ent a m ll isom t part le m h m lle th n 1 μ ı l ea ize

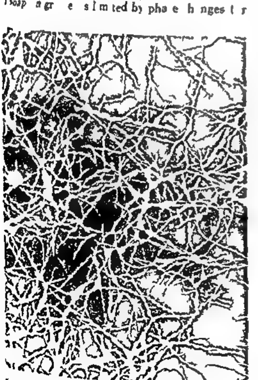


Fig. 5. Elect m g ph of g t t 0,000 ( ) So p-th k ed g g ease. (b) Dye-th k d

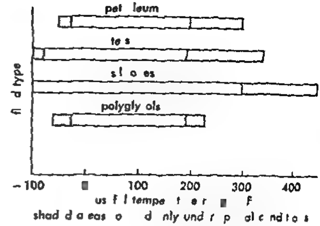
upon to keep engine parts (oil screens ring grooves) clean and this is accomplished by th use of n called detergent oils Performance is il lustrated in Fig 3

The most commonly u ed dispersants are alka line earth salts Of the ■ the most successful have been the salts of petroleum sulfonic acids phenates alicylates thiopho phates and oxidized olefin phosphorus pentasulfide reaction products The e materials owe their effectivene s partly to their urface activity which ensures that foreign parti cle are kept in suspension in the lubricating oil and partly to their alkalinity which enables them to neutralize combustion acids that would otherwise catalyze the formation of lacquers

Polymeric additives have been introduced for di persancy They are copolymers of a long chain methacrylate for example lauryl methacrylate and a nitrogen containing olefin such as vinyl pyr rolidone These nonash dispersants are uperior to the metal containing additives for low tempera ture operation and can be u ed very effectively in motor oils Because they are less alkaline than me tallic additives the polymeric additives are le ef fective in diesel engines who ■ fuel often lead to combustion products which are much more acid than those from gasoline

Boundary lubricants Boundary conditions are encountered in many metal forming proces es in which the pressures required to deform the metal are too high to allow an oil film to form In uch applications fatty oils such as palm oil or lubri cants containing fatty materials are employed to reduce the friction and wear the fatty acids react with the metal surface to form a tenacious oap film which provide effecti e lubrication up to tem peratures approaching the melting point of the soap usually about 120 C See MACHINABILITY (METALS)

Synthetic oils During World War II synthetic lubricants were extensi ely employed by Germany as substitutes for mineral lubricants which were in hort supply Some of these such as the ester oils were in fact superior to mineral lubricants in some



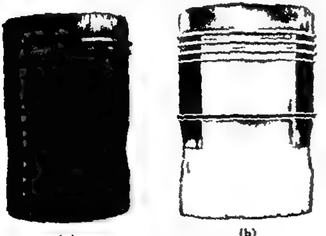
Fg 4 Usef l temperatu e range of synthet c o ls

applications Since the war the u e of synthetics for pecial applications where their performance ju tifies the higher co t has teadily increa ed Their main advantage ■ that they have a greater operating range than a mineral oil (Fig 4) E ters such as 2 ethylhexyl sebacate containing oxidation inhibitors and sometimes mild extreme pre ure additives are used as lubricants for aircraft jet en gines Silicone although ideal with regard to ther mal stability and viscosity characteristic are poor lubricants for steel on teel and this has re tricted their u e although they are invaluable in some ap plications Another class of widely u ed synthetic oils are the polyglycols such as polypropylene and ethylene oxides The e polymers are available in a wide molecular weight range and they vary con siderably in solubility in water and hydrocarbons Thus water base lubricants may be formulated which are employed when a fire hazard exi ts

Solid lubricants The most useful solid lubricants are those with a layer structure in which the molec ular platelets will readily slide over each other Graphite molybdenum disulfide talc and boron nitride possess this property

The principal difficulty encountered with the use of solid lubricants ■ that of maintaining an adequate lubricant layer between the sliding metal surfaces If the solid lubricant is applied as a su pension in a fluid there is a tendency for the par ticles to ettle out and they may not reach the re gion where they are required If they are applied as a thick pa te to overcome the tendency to ettle out it is frequently difficult to force the pa te through the narrow clearances between the liding surface A third method ■ to pretreat the surface with a relatively thick film of solid lubricant us pended in a resin and bake it n Difficulties may then ari ■ through progressively increasing clear ances as the film wears and of course there is no method for its continuous renewal Materials such as graphite and molybdenum disulfide oxidize quite rapidly in air at 400 C Unle s air can be exclud d therefore alternative solid lubricants will be re quired at temperatures greatly in exce s of thi

A unique type of solid lubricant i pro id d l the plastic polytetrafluoroethylene (PTFE) It



( ) (b)

F g 3 The effect of d spe s ts on clea l e (a) Or d nary o l (b) Same ■ l cont n ng d pe sa t add t e

h ted by frict and by heat transfe from the hot engine parts, coll cted c led nd pump d back int the e gin I aut m b le th oil r t rns by gr ity t the rank The air m t n er the tside f the rankc is u lly ffic e t to cool the o l. It is then p mped f m the c ank case ba k to th il distributi g galle es n th gine. I high utput es the il i pumped f m th c ank se nto a sto ge r serv and then through an air o w i ooled heat ex hanger n the y back t the ine.

In pla.h l bri t n, the l nt ri g the e gin flo s to t o ghs into hich e te s f the n necting ods dip (Fig 1) Th dipp ction fo ces il th gh h les in the b se of the s ps t the c nnecting od bearing nd th pray pro- d ced the t gh d trib tes o l t the cyl d alls f om hich t d ips and r n by gr ty int passages t ther b ing

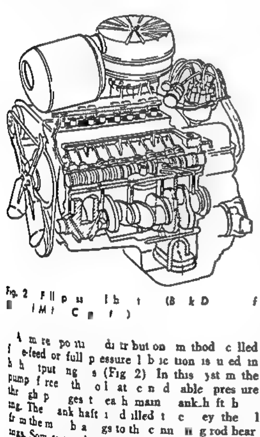


Fig. 2 F ll p ss l b t (B k D f I M I C f)

A m re po iti di tr but on m thod c lled f e-feed or full p essure l b ic tion is u ed in h h tput ng s (Fig 2) In this yst m the pump f rce th o l at c n d able pres ure thr gh p ges t ea h main ank h ft b ing. The ank haft i d illed t c ey the l fr m the m b a gs to th c nn g rod bearings. Som tim s the o necting rod d lled to arry the l t the wri t p ns E cept th larg t engines, the cyl nd r walls lub ated by l ak p y f m th d f th nne ting od bearings. In the f rce-fe d y tem the p mp p es- ure ins res a te dy epl c m nt f the l wh h ha been h ated by f t work w th f h l l f m th e r nkca r serv i l th w y the t mper t d th ef e the w k o ty f the l n th be are o t ll d

Wear c e the l br c ti g l fl w t all p t f th k e, t mport nt tl t t d n t ry k r e m t r l w th t S h m te- rnal m y c me fr m the combu tion of th f el f om dirt n the ind t d air fr m part f the e g itself It mmon t e to filt r all or p rt f the o l t flows thr gh the sy tem to ed e we A large part of the cylinde w r oc rs dur g t rting and b f r the eng h warmed p Cold oil b ng quite iscou l w to h th beari and the end le k ge pray nto the cylinde wall greatly ed d At low engine tempe tu e there is an in ea ed tend ency f rr i products f mb tion to con d n o the cylind w ll Ch mi al additi es are d in mode n e g n il to increase the isc ty index red rr i action and sludge and m il perfo m nce in riou th w y

Exce si e use f l m y b a d by w f yl nd bo il of improper ty l kag pa t the shaft seals loss of vapor from the c ank b th By d n d m ntenance l mpt n can be made mall. The p incipal object on t hi h o l fl w into the comb t n sp ce m ky xh t f uling of k plugs and bon dep s ts in the cylinders S LUBRICANT

[A R R]

Lumber manufacture

The w g of logs int mm ally usef l boards dim n lumb o t mber d the drying and planing to finished p tt rns and size Lumber p o- d t in th United St t m e 1950 has g d around 38 000 000 000 board feet per y ar f whi h b t 80% is softw d and the emainder h dw d *See* WOOD (ANATOMY AND IDENTIFICATION) XYLE A board f t s b a d l ft quare and l thick, or t qui alent in oth dimen ns In the Unit d Stat the ftwood lumber industry s concentrat d in the West and in the S uth Hardwood lumbe p oduced primarily in the G eat Lak states th Appal chians and in outhern wamps and ri e b ttoms whe cypre s s also awed *See* LOGGING (FORESTRY)

Sawmill operation Log are t red t the mill in a l g pond n dry gr und to be mo d l ter to the con ey chain h st, th sy tem which d li e s th m nto the mill Land st d log must b sawed p omptly to a d dete or t on from fungi and sect In the mill l are sawed by a ir ular w a b d saw or a log g ng aw (e SAWING) The cir lar w cir ular sheet f t l ar und the dge f which are cutti g teeth ri ly h p d f d ffe ent types f s wing Band s w e dle band of teel runni g e tw whe l d h e c tting teeth n o or both edge A log g w c n st of st el f ame in whi h th aw ar nd du lly pla ed with the d ired d tance betw en them Ten on i appli d t the aw and th frame s th n mo d ap dly p and d wn w th a l ght f rward o ll ti g t n on the d w r tti g. t k Log fed th o gh the g g w e firmly h ld b ur r ll t a s t aight tt g

Th ck l he d ws w th r pl bl te th e d w th m ll port bl mills b cause thi

Silica particle are round and ome clay particles are plates Forces of interaction between ilica clay particles and oil are easily destroyed by wa ter o it is necessary to waterproof the primary particles by special treatments Electron micro graphs of various types of greases are hown in Fig 5

Mechanical properties of greases When the ap plied tress exceed the yield stress the grea e flows and the viscosity falls rapidly with further increa e of stress until it reaches a value only a little higher than that of the base oil This fall in visco ity is largely reversible since it is caused by the rupture of network junctions which following the release of stress can reform However con tinued vigorous shearing usually results in the rup ture of fibers and permanent softening of the grea e Here certain greases such as those derived from lithium salts of hydroxy acids are superior to other types although the manner of grease prepa ration exerci es considerable influence

In a major grease application for example ball and roller bearings shearing between the races and rolling elements is extremely severe The rea son why a good bearing grea e doe not soften and run out lies in the fact that only a very small frac tion of the grease put in the bearing is actually subjected to shearing As soon as a freshly packed bearing i et in motion most of the grease is re distributed to places where it can remain static in the cover plate recesses and attached to the bore of the cage between the balls or roller The mall amount of grease remaining on the working sur faces of the bearing is quickly broken down to a soft oily material which lubricates these parts and because it has only a low viscosity it develops very little friction

A number of methods exist for the measurement of yield stress and viscosity at various tempera tures One of the oldest of grease test still uni versally used is a consistency (hardness) test in which the depth of penetration of a cone of stand ard weight and dimen ions is determined However few of the many tests used are helpful in predicting the performance of a grease Consequently in de velopment work recourse is made to actual per formance data and to the use of rigs that simulate field conditions *See* BEARING ANTIFRICTION GEL PETROLEUM PROCESSING [R G L]

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Lubrication engine

Continuous supply of a viscous film between mo ing surfaces in an engine during its operation Relati e motion between unlubricated surfaces of engine

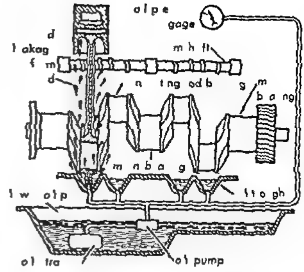


Fig 1 Splash lubricat on (E F Obert Inter l Com bust on Eng nes 2d d Inte nat onal Textbook Co 1950)

parts would result in excessive wear overheating and seizure with destruction of the contacting sur faces The energy loss as ociated with the wear and overheating would be evident in reduced engine power and efficiency The purpose of lubrication is to minimize the e effects by interposing a viscous fluid called the lubricant between the parts Hy drodynamic forces are produced in the lubricant to keep the surfaces separated even though heavy loads are tending to bring them into contact The thi kness of the separating film for a given part geometry depends upon the relative velocity of the two surfaces the absolute viscosity of the lubricant and the load per unit of surface area

Lubricant Engines are generally lubricated with petroleum base oils containing chemical addi tives to improve their natural properties Refining methods and composition may be varied to suit spe cial engine design operating conditions Perhaps the most important oil property is the absolute viscosity which is a measure of the force required to move one layer of the oil film over another With low viscosity a protecting oil film between the parts is not formed With high viscosity too much power is required to shear the oil film in addition the flow of oil through the engine is re tarded

The viscosity of oil tends to decrease as its tem perature is raised It is therefore difficult to main tain the proper viscosity as the engine warms up or as other operating conditions change Visco ity index is a number which indicates the re istance of an oil to changes in visco ity with temperature. The smaller the change in visco ity with tempera ture the higher is the viscosity index I the oil

Lubrication system The function of the lubrica tion y tem is to supply clean oil cool d to the proper iscosity to critical points in the eng ne where the motion of the parts produces hydr dy namic oil films to separate a d support the ru rubbing surfaces In all but the m t primiti e lubricati n sy tems the oil which has l en

ar tr lled L mb r c n be dri d m kil to th desired mo ture o te t m h more pidly than t d y F r example in k lns l in green th m j n l mbe can be dr d to l c mo tu e t nt i2 h u (Fig 3) M h ftwood lum l k l d d not ly t edu ts w ht and u e f ht b t also t gr e t bette util ty M t ha d ood lumber is nly dr d t sawm lls and h pped r h Th s be u e f the diffi ulty of r p dl dry g m t ha dw od and beca e the f h rd ood l mb ch a f rn tur fa t ies, p f r t dry the l mbe th m l that ll they p r ha e from ar us our es will be of l rm m tu e c t nt when u ed Rough dry soft ood l mber i fi h d in pl ning mill u ally nnected th a mills to exa t b d ize or ding or t ce l ng nd flo ri p tterns Finally it graded and sold

Grading F r epar ti n nt eful cl sifi a t l mbe gr d d c d ng to r le pre scribed by m n fa t r d ma ket s c a t All Am r a l mber gr d g ules m t the pecific t s of Am r can Lumbe St nda d de l p d by the U.S D p tme t f Commer The r les ry l ghtly m ng the lumbe p d i r g s b t th y m k all yard and n t u t n l ber nter hangeable i e L mber grad g rules, whi h ba d n th inte ded u e of the l mber re f th e b c typ s O e s y rd lumb r that used in gen r l construct f h e f m and m l st ctures An the i stru tur l lumber f r h a y nd t i l c tructi wh e tr ngth i impo ta t The third i f ct y nd h p

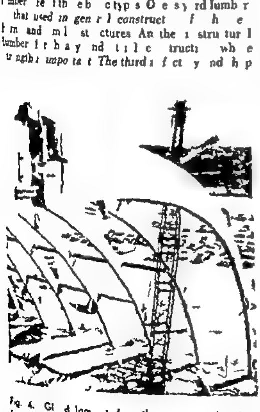


Fig. 4. Gl d lam t d the p ch h h for Al F t 10 000- t p rt mph theatre in W st P lm Be ch Flo d P d g l two f 247 ft th se w ld l g t w d h only 12 sq ed for e t t t l pp rt f th b uding (S th P ne Ass t)

Fig 5 -oll iew f J Al F nt ch h w gh o e 15 t s (W t St t e l)

lumber this cl s i usu lly cut p befor ult mate e Yard and truct ral lumber i graded for se of the p ec a wh le bec us each i of tandard width thickne and length Grades e b s d on th umber and ext f knots pl ts de ay and mil r n tur l defects M ture ont nt nd di m ion pecificat on are also on d ed When l mber t be ed in tructures in wh h stre gth i mport nt the de sity of the gr n ts stra ght ne a d kn t omb nat on that wo ld impair strength r al l ated Nea ly ll h dwood l mb r nd ome ftwood gr ded on the fac t ry nd h p ba bec use such lumber i u ed by f nit e nd other fa t r es wh re t is ut up to lear (o def ct e) pie Hen e hardwo d a d oftwo d hop l mber s gr d d from the po re f c (s rface) whe ea ya d and st ct ral lumb gr d e b ed n the b tte face e of the mp rtan of u ng th r ughly d ed a d c rr tly g aded lumber m h f it s ffic lly g ade marked by ffici l grading ass ci ti ns and t ade marked by n ti ally k wn ma uf tu ers. L mb r f o truct n q lity i st e s ated a d ng t grad ng ules n that rchite ts and en n r ca d ign t ct re l wo d a afely th y an th e f metals o m nry

Laminated wood F b icating wood n p nel beam d t s by gl g smaller piec s f lum be t ether called l m nat ng (s PLYWOOD) The g c ty l larg tree f m wh ch la t mber b wed h t mul t d l m n t ng whi h wa nt d ced into th U ted State in th 1930 Lam n ti g l p m t pref bricat g la ge t e d ar h s t stre gth and e p ci fi ti (s ARCH T USS) In 1954 th lumb r d gl d l m n t d tructu e t t l d 225 4 0 000 boa d ft f h h 90% w s u ed n dges b ild g nd the tr t es D gl s fi d th n p n r th m st w d ly u d wood fo lam at ng th W st and E t re p c t ly b th y b th h e de bl t e gth q l ue Oak l d h efly f mar e l m ate Lam ated wood c n r ad ly be imp eg ted w th p rs t and ret rd t th han ing t ful (F g 4-5) S e FOREST FORESTRY WOOD FI ISHI G WO D PHYS CS WOOD RE FR ATIO [A F W]

B bl g phy N C. B w a d J S Beth l *Li ib* d d 1958

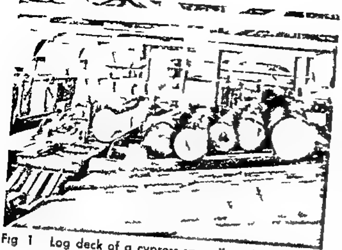


Fig 1 Log deck of a cypress sawmill in Florida showing log conveyor through on right carriage with log being sawed at left and at rear the band saw housing The sawyer is out of view (Photograph by A Leschen and Sons Rope Co)

kind is most readily kept in good cutting condition However they are the most wasteful because their kerf or cutting thickness often is ⅓ in which means that for every four boards 1 in thick that are cut another possible one is lost in the form of sawdust

Logs enter a mill on a conveyor chain and are stored on a log deck They then are placed on a carriage where they are positioned and moved against the saw The carriage is powered by a cable and drum or by a large steam piston As boards are sawed off the log is repositioned for the next cut by a setter who rides the carriage The sawyer standing by the saw operates the carriage the log turning mechanism and the device that moves logs from the deck to the carriage (Fig 1) Some newer carriages have set works that the sawyer operates by remote control All of these operations are quickly performed and there is little unproductive time with skillful sawyers Logs are turned as sawing progresses to obtain the maximum amount of the better grades of lumber As the boards are sawed they are conveyed to the edger if they are to be ripped (made narrower) or they move directly to the trimmer where they are crosscut to the correct length

From the trimmer the boards go to the sorting table where they are separated by grade size and species At some mills the boards are dipped in an antiseptic solution to prevent fungus staining while drying Many of the larger mills use resaws to speed production With them thick cants (large size dimension timbers) are cut on the head saw and then go to a sash gang resaw or to a band resaw that cuts them to final thicknesses Wood waste if needed for fuel is hogged (mechanically chipped) and sent to the fuel house The large wood requirements of the pulp and paper industry have created a market for sawmill waste in the form of chips (see PAPER AND PAPER PRODUCTS WOOD FIBER PRODUCTS) Much wood formerly wasted or used uneconomically is now converted into pulp chips and sold Bark is not acceptable for pulping (see BARK) Therefore at mills that convert their waste to pulp chips logs are debarked before being sawed There are several types of mechanical and hydraulic debarking machines

Sawmills range in size from small portable mills cutting 6000–8000 board ft/day to large ones with two or more headsaws and resaws cutting several hundred thousand board ft/day At portable mills logs are skidded directly to the log deck

Lumber seasoning Lumber is not fully processed for use until it has been dried to a moisture content conforming to that of the place it will be used Otherwise it will shrink or swell and may decay Lumber is air dried in stacks in a yard where air can circulate through it (Fig 2) When air dried it contains about 18% moisture in terms of its oven dry weight Air drying requires from 3 weeks to a year or more depending on the kind of wood its thickness and the weather For faster drying and to attain lower moisture contents than are possible by air drying dry kilns are used These are chambers in which stacked lumber is placed air circulation is forced and temperature and humidity

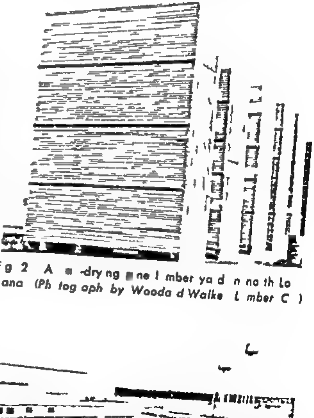


Fig 2 Air-drying pine lumber yard in north Louisiana (Photograph by Woodard Walker Lumber Co)

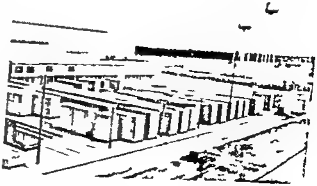


Fig 3 A battery of dry kilns at a southern pine sawmill in Texas showing lumber stacked on trucks ready for placing in the kiln (Photograph by Kirby Lumber Corp)

cla. ific ti n based on p r istenc of the aftergl w not m aningful because it depends on the pr p-erties f the detect r ed to ob erve the l m es-nc W th appropr ate instrume ts one n detect aftergl s l ting o more th n few th andth f a m r seco d, wh ch would b imper ptible to the hum n ye. The ch racter zatio of uch a lu minesce e a either flu r cence or ph pho es-ence therefore d pe d po whethe the bserv u is made by ye r by in trumental mean These terms a ne erthel ss c mm nly used in the sense d fined he e and are on ient fo m ny practi al purpo es Ho e er th y can b g en mo p eci e m ing Fluo e cen e may be de-fined luminescence emiss n ha g an aft r gl du ti which temp atu e-ind pe dent. Ph phoresce ce m y be defi ed a lumine ce ith afterglow du ti wh h bec me sh t r th increa. g t mpe ature F r details n ar m t pes of lumi ence e BIOLUMINES-CE CE CATHODOLUMI ESCENCE CHEMILU II ES-CE CE ELECTROLUMINESCE CE FLUORESCENCE PHO PHORESCE CE PHOTOLUMINESCENCE THER MOLUMINESCE CE

Because of th r m y pract l appl cat s, mat al that g e s ble luminesc ce ha e been st d ed d devel ped mo e t n ely th n those h h emit in th pectral regi ns Lumi esc e, h ev r m y on t f radiati in ny egion f th el t magnetic spectrum The p o-duction f rad tion by th bombardm t f a metal ta get by fa t lectro b am i n ex mple f lum esc Certa flu re ce t l mps call d bla k l ght lamps, a e coated w th a lum escent po der ch se for ts ab l ty t emit ult l t light of pp o imat ly 3600 A the th i bl l ght (s ULTRAVIOLET LAMP) A numbe f lum nes. t sol ds ha e b n de el ped wh ch lumi nesce n the e r i fra ed und x tation by ibl l ght r by th de-ray b m

The b l ty to lum sce i t c nfined to any partı ular tate of m tter Lum e i b-served in gases, l q ds, nd sol d The pas g f an electr al d sch g thro gh a gas will e t the g seou t m m lecul t lumi esce u d rai nd ti ns. A mple f such a g eo luminesce e s the me ry p r lamp in whi h an lectr c l d scha g e tes the me c ry ap t emit both i ble a d ultr i l t l ght (see MER CURY VAPOR LAMP) M ny l qu ds, uch as il ad ti f c rta n d t ff i u sol nt lumi esce ery t gl nd ultr let l ght. A larg umber f sol ds, l ding m y tu al min al as ll th usa d f synth ti in r ni c d g n c compo d l m sc nder ario types of e t i o The maj ppl cati f luminesc e l e sol d l m nesc t m t als.

Th t m g h ph r g ally ppl d t t sol d that h b ted l g ft gl ws, has b ex t ded t in l d y lum esce t sol d g rdle f t gl w p pert Oth terms som t m sed ynonym ly th ph ph r e l m n phor r fl h The te m lum ph r p fe able, nc t r n tat th t aft rglow time are l ng or sh rt In nf rm ty w th urrent u ge, howe r the term ph phor will be u ed in the ucceedi g di cu sion of ol d luminesce t ma te al

Compar ti ely few pure solids lumi esce effi c ently at lea t at normal temper tures In the i teg ry f organ olids the p re aromatic hy droc bo s, such naphth lene and anthracene wh li c ns t ex lusi ely f conde ed phenyl ring a e luminescent as re many hete ocyclic cl d ring mp nds How er the losed phe yl r g st ucture is not in i lf a gu ntee of effi ient l m n sce ce ince ert i s b tit nts for hydr gen the t uctu particul rly halogens tend to educe luminescence efficie cy Am ng the pu i organ c s l ds that lumine effi ently at room temp tu are the tu gst t s ur nyl s Its pl t ocy nide and numb r of salts of the are-e rth el ment

Activators The de elopme t of a large number f in rg n c ph sph is d e to the di c ry that rta n impu ties, lled tivat s, whe present in mount ng from few parts per million to al p r ce t can confer l minesce t pr perti on the comp nd n wh li they inc p t d (h t o m t ix comp unds) Mang n e is a part c larly effect e cti at in a w de ariety of m t ces wh n n por t d in am nts ang g f om mall t ace up to the d of sev l per cent. The miss pect um of the e m ane e-a ti ted pho ph s ge ally l es n the green yel l w or ge sp tral egi s. Other f q ently u ed acti at are copper s l e thallium lead m chromium t tanium, timony a d ti The m t mp rt t ho t m t rials il cat phos-phates ulfide l ide the alkali hal des and xid s of al ium m gnes um bar m, nd zin P ep ti n of ph pho nd the incorpo ation of th act t is g n ally d e by high t mper t rea t n f well m d finely ground powder f th comp n nts.

In o de fo lt a iolet l ght t p m ke lum e ce a h t c the b tance must b ble t bso b t. Bec f variati s n t bil ty to bso b ltra olet l ght f diffe ent wa e-l gths, m t ial may be n luminescent u de ult i let l ght f one w elength a d tr gly lum nescent u d d fferent w le gth n th lt i let eg n F r a simil r a ub ta n m y not lum der ultr vi let l ght t all d yet b t gly l m sc t under x y rra d tion

LUMINESCENCE IN ATOMIC GASES

The processe th t ur in l m escen e may li most imply ill t ted n the c of an t m a gas. The t m e t ly in e l in pec fi t te f gy som f which i hown sche-m t ally n F g 1 Th l we t en gy le el of the t m E c rre po ds to th i m t in xcit d or gro d, tate, and the h gher e gy l els, E nd E ep t electr nic lly ex ted t te f th t m Th t t f th t m f m tat E t t te E equires th bso pti f a am unt f

Lumen

The unit of luminous flux It is defined as the luminous flux emitted within a unit solid angle (1 steradian) by a point source having a uniform intensity of 1 candle It follows therefore that a light source having an intensity of 1 candle in every direction will be emitting a total luminous flux of 4π lumens

The lumen is also equal to the luminous flux received on a unit surface all points of which are at a unit distance from a point source having a uniform intensity of 1 candle

The output of light sources is given in lumen See CANDLE LUMINOUS FLUX [R C P]

Lumen hour

The unit of quantity of light It is the quantity of light (luminous flux) radiated or received for a period of 1 hour by a flux of 1 lumen Similarly other units that can be used to measure the quantity of light are the lumen second or the million lumen hour

The symbol of the lumen hour is Q The equation is

$$Q = \int F\,dt$$

where t is time in hours and F is the luminous flux measured in lumens See LUMEN LUMINOUS ENERGY PHOTOMETRY [R C P]

Luminaire

An electric lighting fixture wall bracket portable lamp or other complete lighting unit designed to contain one or more electric lighting sources and associated reflectors refractors housing and such support for these items as is necessary

Luminaires for general lighting are classified by the International Commission on Illumination in accordance with the percentages of total luminaire output emitted above and below the horizontal into direct or indirect types with intermediate classifications of semi direct semi indirect and general diffuse or direct indirect

Luminaires for floodlighting or for street or highway lighting are classified according to beam spread or according to candle power distribution patterns for the specific applications See ILLUMINATION [W B B]

Luminance

The luminous intensity of any surface in a given direction per unit of projected area of the surface viewed from that direction The International Commission on Illumination defines it as the quotient of the luminous intensity in the given direction of an infinitesimal element of the surface containing the point under consideration by the orthogonally projected area of the element on a plane perpendicular to the given direction Simply it is the luminous intensity per unit area Luminance is also called photometric brightness

Since the candle is the unit of luminous intensity the luminance or photometric brightness of a surface may be expressed in candles/cm² candles/in² and so forth

Mathematically luminance B may be found from

$$B = dI/(dA \cos \theta)$$

where θ is the angle between the line of sight and the normal to the surface area A considered and I is the luminous intensity See LUMEN LUMINOUS INTENSITY

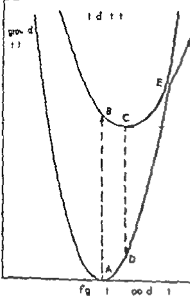
The stilb is a unit of luminance (photometric brightness) equal to 1 candle/cm² It is often used in Europe but the practice in America is to use the term candle/cm in its place

The apostilb is another unit of luminance sometimes used in Europe It is equal to the luminance of a perfectly diffusing surface emitting or diffusing light at the rate of 1 lumen/m² See PHOTOMETRY [R C P]

Luminescence

Light emission that cannot be attributed merely to the temperature of the emitting body Various types of luminescence are often distinguished according to the source of the exciting energy When the light energy emitted results from a chemical reaction such as in the slow oxidation of phosphorus at ordinary temperatures the emission is called chemiluminescence When the luminescent chemical reaction occurs in a living system such as in the glow of the firefly the emission is called bioluminescence In the foregoing two examples part of the energy of a chemical reaction is converted into light There are also types of luminescence that are initiated by the flow of some form of energy into the body from the outside According to the source of the exciting energy these luminescences are designated as cathodoluminescence or electronoluminescence if the energy comes from electron bombardment radioluminescence or roentgenoluminescence if the energy comes from x rays or from γ rays photoluminescence if the energy comes from ultraviolet visible or infrared radiation and electroluminescence if the energy comes from the application of an electric field By attaching a suitable prefix to the word luminescence similar designations may be coined to characterize luminescence excited by other agents Since a given substance can frequently be made to luminesce by a number of different external exciting agents and since the atomic and electronic phenomena that cause luminescence are basically the same regardless of the mode of excitation the subdivision of luminescence phenomena into the foregoing categories is essentially only a matter of convenience not a fundamental distinction

Fluorescence and phosphorescence A second basis frequently used for characterizing luminescence is its persistence after the source of exciting energy is removed Many substances continue to luminesce for extended periods after the exciting energy is shut off The delayed light emission (afterglow) is generally called phosphorescence the light emitted during the period of excitation is generally called fluorescence In an exact sense this



Fg. 2 C fig t coo d t rves f mpl lum ent c t r T to $A \rightarrow B$ h w b p- ton nd fr t $C \rightarrow D$ h w m Th gy E_Q th t ry f r th t d t to t ch th point E f m wh ch t t t th g d t t an be d w tha t l m

curves the n gy of the gr d a d e ned tate is sh n to y parabolically as some fig ra tion oo d nate, us ally th di tance f m th lumi esc t t to it n e t ne ghbor ha ged There is l e f the c ord ate for wh ch th en gy is m um m b t thi value d ffe ent f th gr nd a d e ted tat s because f the d ff r ent int a t o f the lumi e t cente with m a ghbo s. Absorpt on of l ght g es ri e t th tra t f m A to B Th t t oc urs so p dly that the o ar d the l mi e nt ce t do n t b e time t n ar ge. Once the yst m at B it gi es p he t e gy t its urr ding by me l l tt ce b at ns and reach s th new equil b um po t o t C (e LATTICE VIBRATIONS) Em ssio or h th y tem mak the t n t tio f m C t D and n agai h t ene gy i gn p h n th sy tem g es f m D b ck down t A It t th l ss of en gy i th form of he t hich uses th n ergy a soc at d w th th em s- sion $C \rightarrow D$ t b l th n th t soci t d w th th bsorpti $A \rightarrow B$

Wh n the y t m t at n q libr um p nt such C i th ted tat urve t s t t ne b t m g t er a mall eg n arou d C be e f th th rm l gy f the sy tem At high t mp r t th e fl tu t e a lar e f co figu ti n coord te A a e- nt th m n t t a t ju t t n t D n d B In th n ty f D th g d t t un h rap d) g f rgy so th t d t l d t a l ge r g i e g e n the

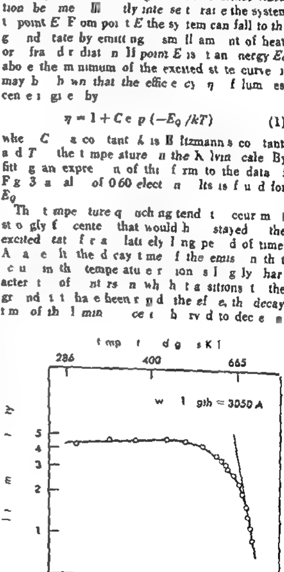
pt cal tr n ti n This explain the broad emi ion and abso pt on bands that are bserved An an ly si of th so t p edict th t the widths of the band (usu lly mea n ed in energy nit bet en the p int at which th emi on or ab orj tion is half its m x mum v lue) hould v ry s the qu re oot of the temperature For m ny sy tem th s relat n ship is al d f temperatures ne r and above ro m tempe tu

Two oth r phen me a which can be explai d on th bas of the m del de ribed n F g 2 are temperat e que ch ng of lum nescence and the ar tion f the de ay t me of lum e cence with temperat re In F g 3 a urve f temper ture qu ncl ing fo the m ion in thallium ct ted p ta um chl ide is hown At low temper t res there is ry little change in b ight ss with t m pe ture but t ele at d tempe atu the lum nes- ce e d cay rapidly On the hem of Fig. 2 thi interp eted s m an g that the thermal vibra tion be me tly inte se t rai e the system t point E F om poi t E the sy tem can fall to th g nd tate by emitt ng sm ll am nt of heat, or fra d r diat n If point E is t an nergy E_Q abo e the m nimum of the excited st te curve it may b h wn that the effic e cy η f lum es- cen e i gi e by

$$\eta = 1 + C e p\,(-E_Q/kT) \qquad (1)$$

whe C a co tant k is B ltzmann s co tant, a d T the t mpe ature n the K lvin cale By fitt g an expre n of thi f rm to the data f F g 3 a al of 0 60 elect n lts is f u d for E_Q

Th t mpe ture q nch ng tend t ccur m t st o gly f cente that would h stayed the excited tat f r a lati ely l ng pe d of time A a e lt the d cay t me f the emis n th t c u in th tempe atu e r ion s l g ly har acter t of nt rs n wh h t a sitions t the gr nd t t ha e been r p d the ef e, th decay t m of th l min ce t b rv d to dec e s



Fg 3 V t f th B ght f th ll m-a ti- ted p t m chl d ph ph w th t mp t

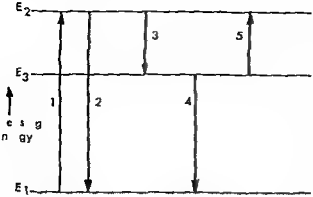


Fig 1 Schematic representation of energy levels and electronic transitions in an atomic gas E_1 ground state E_2 and E_3 excited states 1 excitation 2 emission of resonance luminescence 3 radiationless transition to lower excited state 4 luminescence emission if transition $E_3 \rightarrow E_1$ is allowed (if it is not allowed 4 does not occur and E_3 is called a metastable state) 5 stimulation of atom back to emitting state

energy $\Delta E = E_2 - E_1$ If this excitation is to be produced by the absorption of light the energy of the acting light photon $E_{absorbed}$ must equal ΔE The frequency of the exciting light must therefore be $\nu = E_{absorbed}/h = (E_2 - E_1)/h$ and the wavelength of the exciting light must be $\lambda_{absorbed} = hc/(E_2 - E_1)$ where h is Planck's constant and c is the velocity of light In an isolated atom this extra energy cannot be dissipated and is emitted as radiation when the atom eventually returns to its ground state The emitted light will therefore again correspond in energy to ΔE and will have a wavelength $\lambda_{emitted} = \lambda_{absorbed}$ When $\lambda_{emitted} = \lambda_{absorbed}$ the emitted light is sometimes referred to as resonance luminescence or resonance radiation For further details *see* ATOMIC STRUCTURE AND SPECTRA

If a large number of atoms are excited and the excitation then removed the luminescence intensity will decrease with time exponentially according to the equation $I = I_0 e^{-t/\tau_i}$ where I is the intensity of luminescence at a time t after removal of the excitation I_0 is the intensity at $t = 0$ and τ_i is the average time required by an atom to make a spontaneous luminescent transition The quantity τ_i is independent of temperature and it is this temperature independence that is emphasized in the more precise definition of fluorescence given earlier If the transition between the energy levels E_1 and E_2 is highly probable (a so called permitted or allowed transition) τ_i is very small of the order of 10^{-8} sec for transitions involving visible light

The excited atom can also lose a certain amount of energy and fall to an energy state E_3 of intermediate energy between E_1 and E_2 This can happen for example if the excited atom collides with another atom If the transition from state E_3 to the ground state E_1 can occur with a reasonably high probability fluorescence will occur starting from this intermediate excited state In this case the fluorescent wavelength $\lambda_{emitted} = hc/(E_3 - E_1)$ Since $(E_3 - E_1)$ is smaller than $(E_2 - E_1)$ the fluorescence in this case will be of longer wavelength than the resonance radiation

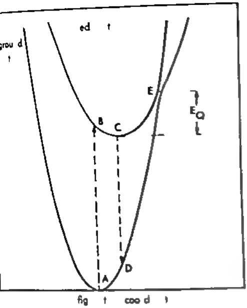
If however a transition between state E_3 and state E_1 is highly improbable (a so called forbidden transition) state E_3 is known as a metastable state The atom can remain in this state for long periods of time and cannot return to the ground state with the emission of radiation Luminescence can occur under these circumstances only if the atom regains the energy $(E_2 - E_3)$ by a collision with another atom or by some other process Once the atom has been brought back to state E_2 a transition to the ground state is again allowed and luminescence corresponding to $(E_2 - E_1)$ will be emitted The existence of metastable states like E_3 explains the delayed emission termed phosphorescence The atom may spend a considerable amount of time in such a state before some external influence causes it to return to an emitting state such as E_2 in which case the luminescence is correspondingly delayed and appears as an afterglow In order for the atom to get from E_3 to E_2 it must absorb energy somehow The rate of return to the emitting state and hence the duration of the afterglow will therefore depend to a very large extent on temperature At high temperatures the atoms will be excited back to the emitting state rapidly and there will be a bright afterglow of short duration At lower temperatures the atom will be raised back to the emitting state very slowly and the afterglow will be of long duration but of low intensity This temperature dependence is the basis for the more precise definition of phosphorescence given earlier

The principles illustrated in the foregoing discussion may be extended with little modification to the case where the primary absorption or excitation act completely removes an electron from an atom (that is ionizes the atom) instead of merely raising the atom to an excited state Under these conditions the electron can be trapped temporarily by other atoms and its return to the parent atom can also be delayed by this mechanism

CONFIGURATION COORDINATE CURVE MODEL

Luminescence in atomic gases is adequately described by the concepts of atomic spectroscopy but luminescence in molecular gases in liquids and in solids introduces two major new effects which need special explanation One is that the emission band appears on the long wavelength (low energy) side of the absorption band the other is that emission and absorption often show as bands hundreds of angstroms wide instead of as the lines found in atomic gases

Both of these effects may be explained by using the concept of configuration coordinate curves illustrated in Fig 2 As in the case of atomic gases the ground and excited states represent different electronic states of the luminescent center that is the region containing the atom and/or molecule involved in the luminescent transition On these



g. 2 C fig t oo d t rv s f o mpl esc nc t T t $A \rightarrow B$ sh w b rp- on, nd tr nsiti $C \rightarrow D$ sh w m Th gy g th t ec sory f th ted t t t th o t E f m which t t t th g d t t n be mod w th t l m sc

urves th e gy of th gr d a d exc ted st t sh n to ry pa bol lly som fig ra o coo di ate, u ally the di tance f m the l mi esc t e t t it re t neighbors, i hanged Ther is a al e f the coo d t f r wh l the energy is a mi im m b t th l e d ff r nt f r th ground d e t d t te bec u e f th diffe ent inter ti f the l m esce t ce te with t ghbors. Abso ptı n f l ght gı es e t the tran tio f m A t B Th s tra sition occu so rap dly th t the n aro d the l m sc nt ce t do n t ha tim t earr ge. O e th y tem t B t gi es p he t e e gy to m d ng by m f latt e b at a d he th ew equilib um po t o t C (LATTICE VIBRATIO S) Emi occu s h n the y tem m k the t i tion f m C t D d nc gai h t e gy is gi en up h th sy tem goes fr m D b k d wn to A It thi l f n th f rm f h t hi h ca ses th e gy so ted w th th mis- n $C \rightarrow D$ t be les th th t soc t d w th the absorpti $A \rightarrow B$

Wh the y t m at a eq l b m po ti n h C f the ted t te rve it t t rest b t migr tes m ll eg d C bec se f th th rm l gy f th y tem At high t mp tur the fluct t nd g l figu t n oord te. A e- sult, th emi tr t t j t t p t D th gr d t te rv but und D l th ty f D th gr d tat rı h w a p d h g f ergy th t m ll ang f l f r th o figur t di t l d t l f n ge in th

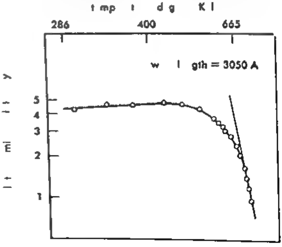
jt c l tr nsit n Tl explai tl e br ad mi i n d absorj t n b nd th t are b r ed An a aly is f th sort j redi ts tl at tl e w dth f tl e l and (u ally mea ur l e ergy n it l etwe n the po nts t wl ich the mi i n r ab rj ti is l alf t m im m lue) l ld ry the q re r oot f th t mperature F r many y t m tl i r lat m hip is lid f r temper ture near and abo r m temperat re

Tw tl er j he me wl i h c be xj l in d n tl e b is f tl e m d l l scr b l in Fig are t mp ratur j ncl g f lumin sc ce nd tl e ari ti n f the de ay t me f lum ce e w th t mj er ture. In Fig. 3 a urve f t j rat re j encl ing f r tl e em i n i tl llium ti ted pot ium lll id i l w At l w t mperat r tl r i v ry l ttle cl ange in brightne with t m p rat e b t at l t d t mj e ture tl lum n s ce de ys rap dly O the scheme f Fig. 2 thi interpr ted s me ing tl t the therı l tl ra t n l ec me ffi e tly i t n e to r i e tl e y t m t po nt E Fr m point E the y t m n fall t tl gr und t te by mitt g a m ll am u t f heat, r frared r diat lf po t E t an energy E_Q bo e th min m m f the exc ted state r e, it may be l wn that tl e eff i cy η f lumines- e ce gi n by

$$\eta = 1 + C \quad p\,(-E_Q/kT) \qquad (1)$$

where C a c n t t k is B ltzmann c t t and T is tl e t mperatu e n the Kel i scale. By fitting pre f th f rm t the data f Fg. 3 a l f 0 60 l ctr n lt i f i d f r E_Q

This t mp r ture que h g te d t oc r m t t gly f r te tl at w ld l tayed in tl e ex t d t te f a l tı ely l g j d f t me A a r lt th dec y t m f tl e emi ion that in th t mp ratu e eg larg ly h r t tie f c t m which tran ti ns t the gr u d t t ha e been p d tl er f e, the de y time f th l minescen e s bserved t decr a e



Fg 3 V t f th b ght f th ll m-o t t d p t m hl d ph ph w th t mp t

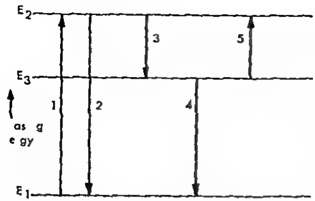


Fig 1 Schematic representation of energy levels and electronic transitions in an atomic gas E_1 ground state E_2 and E_3 excited states 1 excitation 2 emission of resonance luminescence 3 radiationless transition to lower excited state 4 luminescence emission if transition $E_3 \rightarrow E_1$ is allowed (if it is not allowed 4 does not occur and E_3 is called a metastable state) 5 stimulation of atom back to emitting state

energy $\Delta E = E_2 - E_1$ If this excitation is to be produced by the absorption of light the energy of the acting light photon $E_{absorbed}$ must equal ΔE The frequency of the exciting light must therefore be $\nu = E_{absorbed}/h = (E_2 - E_1)/h$ and the wavelength of the exciting light must be $\lambda_{absorbed} = hc/(E_2 - E_1)$ where h is Planck's constant and c is the velocity of light In an isolated atom this extra energy cannot be dissipated and is emitted as radiation when the atom eventually returns to its ground state The emitted light will therefore again correspond in energy to ΔE and will have a wavelength $\lambda_{emitted} = \lambda_{absorbed}$ When $\lambda_{emitted} = \lambda_{absorbed}$ the emitted light is sometimes referred to as resonance luminescence or resonance radiation For further details *see* ATOMIC STRUCTURE AND SPECTRA

If a large number of atoms are excited and the excitation then removed the luminescence intensity will decrease with time exponentially according to the equation $I = I_0 e^{-t/\tau_l}$ where I is the intensity of luminescence at a time t after removal of the excitation I_0 is the intensity at $t = 0$ and τ_l is the average time required by an atom to make a spontaneous luminescent transition The quantity τ is independent of temperature and it is this temperature independence that is emphasized in the more precise definition of fluorescence given earlier If the transition between the energy levels E and E_2 is highly probable (a so-called permitted or allowed transition) τ_l is very small of the order of 10^{-8} sec for transitions involving visible light

The excited atom can also lose a certain amount of energy and fall to an energy state E_3 of intermediate energy between E_1 and E This can happen for example if the excited atom collides with another atom If the transition from state E_3 to the ground state E_1 can occur with a reasonably high probability fluorescence will occur starting from this intermediate excited state In this case the fluorescent wavelength $\lambda_{emitted} = hc/(E_3 - E_1)$ Since $(E_3 - E_1)$ is smaller than $(E - E_1)$ the fluorescence in this case will be of longer wavelength than the resonance radiation

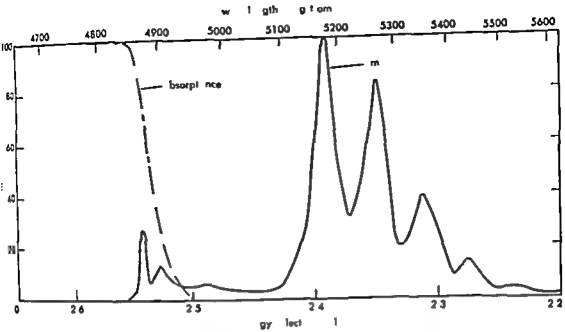
If however a transition between state E and state E_1 is highly improbable (a so called forbidden transition) state E_3 is known as a metastable state The atom can remain in this state for long periods of time and cannot return to the ground state with the emission of radiation Luminescence can occur under these circumstances only if the atom regains the energy $(E - E_3)$ by a collision with another atom or by some other process Once the atom has been brought back to state E a transition to the ground state is again allowed and luminescence corresponding to $(E - E_1)$ will be emitted The existence of metastable states like E_3 explains the delayed emission termed phosphorescence The atom may spend a considerable amount of time in such a state before some external influence causes it to return to an emitting state such as E in which case the luminescence is correspondingly delayed and appears as an afterglow In order for the atom to get from E_3 to E it must absorb energy somehow The rate of return to the emitting state and hence the duration of the afterglow will therefore depend to a very large extent on temperature At high temperatures the atoms will be excited back to the emitting state rapidly and there will be a bright afterglow of short duration At lower temperatures the atom will be raised back to the emitting state very slowly and the afterglow will be of long duration but of low intensity This temperature dependence is the basis for the more precise definition of phosphorescence given earlier

The principles illustrated in the foregoing discussion may be extended with little modification to the case where the primary absorption or excitation act completely removes an electron from an atom (that is ionizes the atom) instead of merely raising the atom to an excited state Under these conditions the electron can be trapped temporarily by other atoms and its return to the parent atom can also be delayed by this mechanism

CONFIGURATION COORDINATE CURVE MODEL

Luminescence in atomic gases is adequately described by the concept of atomic spectroscopy but luminescence in molecular gases in liquids and in solids introduce two major new effects which need special explanation One is that the emission band appears on the long wavelength (low energy) side of the absorption band the other is that emission and absorption often show bands hundreds of angstroms wide instead of as the lines found in atomic gases

Both of these effects may be explained by using the concept of configuration coordinate curves illustrated in Fig 2 As in the case of atomic gases the ground and excited states represent different electronic states of the luminescent center that is the region containing the atom and/or ... involved in the luminescent transition On the

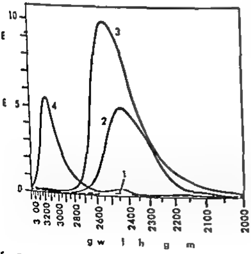


Fg 6. Th bsorpt (100 m p t f t m) d dg m o of dm m lfd t 4 K

bo nd lectr s i low diele tr c c tant m teri l hile the lo g a g inter t on d m ates for loosely bound lect i high d lect ic c t t mat ials.

SENSITIZED LUMINESCENCE

A p oces f co d bl tere t occu in ys-tems here ne type of ctı t r abso bs th e u g l ght nd t fer it e rgy t a sec nd type f cu t h ch then em ts. The tran f r doe n t n l m t n of electr Th proce s is fte call d tized l minesce ce, and the principal pho ph u ed i fl oresce t l mp are



Fg 7 Ex t t p t f m g m f l bo t (C CO) ph ph w th d ff t p ty t rs 1 t 2 th ll m 3 le d 4 m

f thı type The r ult m lcium arbo te (CaCO) h wn in Fig. 7 ll trate thi l d f y t m If di l nt mang ese (Mn) al i in porated a n actı t r t CaCO th y t m gı e ly a ry w k Mn m i f r ll wa e l gth f xc t g ult let l ght Tl becau e the M i fha ly f rb dd n t tı n in th pectral r gı n h wn by it ry l w bsorptı n t e gth d slow decay f l m esc e. In ther w rd th M d es t abso b ry mu h lt l t l ght Br ght pho ph m y b pr pared by i porat ng di ale t l ad (Pb) m n alent thalli m (Tl) r tri l t eri m (Ce) l g with Mn^{++} in CaCO In a h c e the Mn m s-i th ame, b t the w l gth wh ch excite these pho ph rs y s the tl t at (alled the itize) ı ch ged All these absorpti ns occ f r ne g well bel w the e ergy t wh h f e lectr a formed the solid Th l n i that th ltra i let l ght i bso bed by tl e Pb Tl Ce ⁺⁺ sen t wh h p ss the en gy to ne by Mn act t s a d exc t the M em

It i imp t t to know ver what d ta s the rgy m y b tran ferred from bsorb r i em t t r E p m ts on calci m ilicat w th Pb^{++} a d M dded mpu t es l n h w th t if M is y n f the 8 nea t latt e t a nd th Pb^{++} the e ergy tra fer m y take pl

Th t f f gy h b treat d theo t lly ng q a tum me h d um g a m d l f e o a e b twee pled y tem A n mbe f h e b en amı d i cl e th t h an ll w d tra t n ce ly th n e w ll it abso b the ex t g l ght p-p e bly Th fi t e ts n wh h the tı t r underg a ll w d tra t The p b-

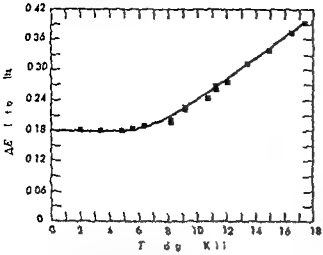


Fig. 4. Variation of the width of the *F* center absorption band in potassium chloride at its half-maximum points, ΔE, as a function of the square root of the temperature.

Quantum mechanical corrections. Although the configuration coordinate curve model of Fig. 2 is successful in describing many aspects of luminescence in solids, it predicts that emission and absorption bands should become narrow lines as the temperature is reduced to absolute zero (0 K). This is not the case, as is shown in Fig. 4, which gives the width of the absorption band of the *F* center in potassium chloride as a function of the square root of the temperature. (An *F* center is the simplest type of color center, a color center being a lattice defect which can absorb light. For a detailed discussion of the optical absorption bands associated with *F* centers, see COLOR CENTERS.) At high temperatures the previously quoted results are valid, but at low temperatures the width of the band is constant.

This phenomenon may be explained by treating the configuration coordinate curves quantum mechanically. The curves have the energy versus displacement characteristics of the simple harmonic oscillator. For this case the quantum mechanical analysis shows that there is a series of equally spaced energy levels separated by an energy of $h\nu$, where h is Planck's constant and ν is the frequency of vibration. The lowest of these levels occurs at a value of $\frac{1}{2}h\nu$ above the minimum of the classical curve, and this energy is called the zero point energy. Its importance is that even at absolute zero the system is not at rest but varies over a range of configuration coordinates characteristic of this lowest vibrational level. Analysis shows that under these conditions the widths of the band, ΔE, vary as

$$\Delta E = A\,[\coth\,(h\nu/2kT)]^{1/2} \qquad (2)$$

where A is a constant. A curve of this form is drawn through the experimentally obtained points of Fig. 4 and shows satisfactory agreement.

One other result of the introduction of quantum mechanics is that this simple model predicts that both absorption and emission bands should be Gaussian in shape at all temperatures; that is, they should be of the form

$$I = I_0 \exp\,[-A(E - E_0)^2] \qquad (3)$$

where I is the emission intensity or absorption strength for light of energy E, and I_0 and E_0 refer to corresponding quantities at the maximum of the curve. Figure 5 shows the emission spectrum of thallium-activated potassium chloride plotted in such a way that the expression of Eq. (3) would give two straight lines making equal angles with the horizontal. Although there is some disagreement in the wings of the emission spectrum and although the lines are not quite at the same angle, there still is fairly good agreement with the predictions of Eq. (3).

Materials with high dielectric constants. The use of configuration coordinate curves is justifiable only when the electron taking part in an optical transition is tightly bound to a luminescent center and interacts primarily with its nearest neighbors. This appears to be generally the case in materials with low dielectric constants such as the alkali halides. For high dielectric constant materials the situation is very different. It has been estimated that for boron in silicon the electron is spread over about 500 atoms, so that its interaction with the nearest neighbors is small. In these cases the center interacts with the lattice during an optical transition through the creation of many vibrational phonons (sound quanta) at relatively large distances from the center (*see* PHONON). A case of this sort is illustrated in Fig. 6, which shows edge emission in cadmium sulfide near the absorption edge of the material. The major peaks correspond to an optical transition with simultaneous emission of 0, 1, 2, and 3 phonons, respectively, starting with the highest peak. The peaks are equidistant in energy, and the spacing is just that to be expected for the creation of phonons.

Although both short- and long-range interactions of a center with its environment occur in all cases, the short-range interaction dominates for tightly

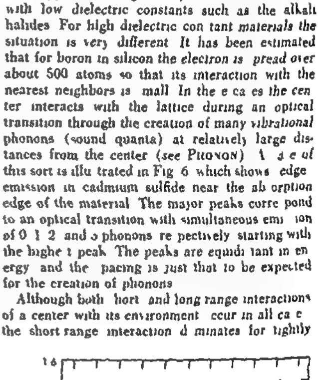
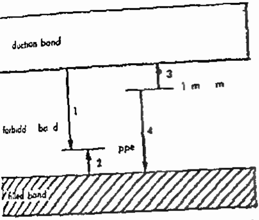


Fig. 5. Emission of thallium-activated potassium chloride at 4 K in a plot of this form. A Gaussian curve would consist of two straight lines making equal angles with the abscissa.



Fg. 9 En gy b d mod l f l m sc p o s ne sulfid w th copp os t ato d lum n m os ocen t r

imp rt nt to n te that n this pr both ele tr ns and h le m t b a med to m

I nnc ulfid the mal act ato ar m no lent metal h a Ag r C Tl ey r j l c Zn ions. T ma t in electr al n t al ty t nec s sary also t rporat nt the latti n n uch a Cl f r S r Al^{+++} f Zn The e add ti al to ar called oa t at rs. Th it ati s w quite c plex, d i illu tr ted f ZnS with Cu a d Al as add d imp ities Fig 9 The ar r in th fig e h w m of tl lectron tran u th t gi ise to b ers ble effect Ar s l a d 4 h w t o d ffe ent l mi esc nt tr t u ns. Arr w 2 h w th stati n f n electr into the l mi sce t e te wh h may oc ur by abso pti n f i red l ght by th mal flu tua u I e th c e th e ter is pr e ted from lumi esc g a d thu is qu ched Tr n ti n 3 the x it ti n of n electr t the du t n b d. The lect m y be st d by th rmal en rgy and ts ppe r ce m y be d te ted b th ppearanc of tr t l Th s p oc c ll d thermol mi esc nce (se THERMOLUMI ESCE CE)

Th de a ty f t an t n a d effects in zin ulfide m kes t diffic lt to ome t firm co cl concerning the d t il f any e y tem At the am time th ari ty m ke lum ne en e m l ng electron m t n o e f th mo t fa t g nd chall g fields of tudy [C.C.A. J H S]

B bli gr phy H W Le e enz, *An Int od ct o t th L mi e of S lids* 1950 P Pri gs h m Fl r s n nd Ph sph e ce 1949 F t nd D Tur b ll (d) *S l d St t Phy* ics, 1.5 19 7

Luminosity factor

Th rati f lum fl x t p rt c la wa length to the rre pond ng di t fl x t the am l gth. It xp d l m pe watt. S LUMEN PHOTOMETRY

The lum n ty factor s fte d n th f rm f th lat e lum n ty fa to which i the r t f the lumin s ty f t f a ert wa ele gth to the l t the wa l gth of ma mum l m sity The Inter t nal C mm t ion Ill i ati n and the Internati l C mm itt n W ght and M as re have ad pt d alues f r r l t e lumin ity fact r as a ba f r e tabl l ment f l h t met ric st dard f typ d ffering fr m the primary tandard i pe tral di tril uti n f light

Mathemat cally the lumi ity fact r K s f und fr m tl e e juati n

$$K = F / I$$

where F s tl e l min us fl I is the radi nt flux and λ d ig ates tl e wa l gth

Tl lum per watt is al tl terr u ed t ex pre the eff ency f an lectric l mp wh h h uld n t be c nfu ed w th lum ity fa tor The eff ency i pre ed as the r tio of tl e tput in lumen di ided by tl e nput in watt [R C P]

Luminous efficiency

Tl rati of th t tal lumi fl x t the t t l adiant fl x Thi i gen ally tated lumen per w tt f r diant flux L n in ff ien y and lum no ity factor ar ynonym u in tl e ca e where energy i radi ted at ingle w le gth Tl e tl eo reti l max mum po ble l mi ffcie cy f ra d t e gy f a source l light c me t a wa e length of 555 m llim t n (t wh ch tl e hum n eye m t n iti) d i 680 lume s pe w tt b ed n the C.I.E. st t p l min ty urs the 1948 Inter ati nal Temperature S al and the n w al e f tl e c ndle S CA DLE LUMEN PHOTOM ETRY

Tl e r r al of the l m no ffi ie cy f r di a t en gy i f eq ently all d th mechani l qui lent f l ght

The l min us e cy f radiant en rgy sh uld n t be n fused w th th effici cy f an le tric l mp B tl ar gi n n term f lum ns/watt but i th fir t c e the w tt ef r t tl t t l radia t flux wh l in the d th watts ref t the p w ppli d t tl e l mp [R C P]

Luminous energy

The ad ant en gy n the ble reg n It n the f rm of le tr mag et c w e a d nce th ible reg n is mm ly taken as e te ding 380- 60 mill mi o i wa length the l min en rgy i co t in d with n that r gi It i equ l t the time t g l of th pr d ti n f the lumi u flux Se LU IEN HOUR PHOTOMETRY [R C P]

Luminous flux

The t m rate of flow of l ght It i radi t flux in the f rm f l tr m g et wa es whi h ff cts the ey o mor st ctly the t m r te f flow f radi t e ergy lu ted c rd ng to ts apa ity to du e al se s ti The i ible spe trum s d nar ly n d ed t tend fr m 380 to m llim n n wa l gth th efo e lumin u fl x i d ant flu i th t reg of th electro m gn t spe trum Th it f m a f lum n u fl the lum S LU IEN PHOTO IETRY [R C P]

ability of energy transfer P (defined as the reciprocal of the time required for a transition to occur) varies as

$$P \propto \frac{1}{R^6 n^4} \int f F_A dE \qquad (4)$$

Here R is the distance between sensitizer and activator, n is the index of refraction of the host material which may be liquid or solid, f is a function describing the emission band of the sensitizer as a function of energy and is normalized so that the area under the curve is unity, and F_A is a function describing the absorption band of the activator, also normalized to unity. The integral of Eq. (4) measures the overlap of these bands and determines the resonance transfer. In typical cases the sensitizer will transfer energy to an activator if the activator occupies any one of the 1000–10 000 nearest available sites around the sensitizer. One type of forbidden transition is a quadrupole transition; in this case the number of sites for transfer would be about 100. If the transition in the activator is even more strongly forbidden, quantum-mechanical exchange effects predominate and the number of available sites for transfer should be reduced to 10 or less. In both of the cases just mentioned the integral measuring the overlap enters in the same way as it does in Eq. (4). From this theoretical treatment it appears that phosphors with Mn^{++} as the activator probably receive their energy by exchange interactions.

Concentration quenching. Another phenomenon related to the resonant transfer of energy is that of concentration quenching. If phosphors are prepared with increasing concentration of activator, the brightness will first increase but eventually will be quenched at high concentrations. It is believed that at high concentrations the absorbed energy is able to move from one activator to a nearby one by resonant transfer and thus migrate through the solid or liquid. If there are "poisons" or quenching sites distributed in the material, the migrating energy may reach one and be dissipated without luminescence. Impurity atoms, vacancies, jogs at dislocations, normal lattice ions near dislocations, and even a small fraction of the activator ions themselves when associated in pairs or higher aggregates can act as poisons. As the concentration is increased, the speed of migration is increased, and the quenching process becomes increasingly important.

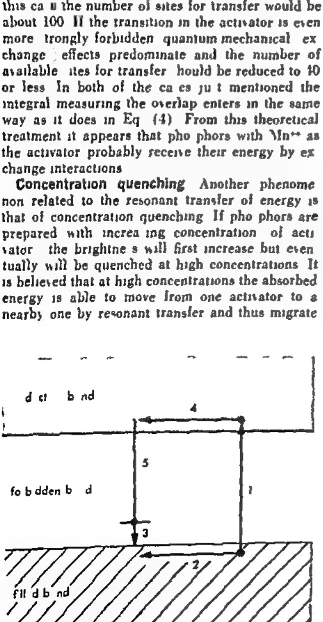


Fig. 8. Energy band model for luminescence processes in zinc sulfide.

LUMINESCENCE INVOLVING ELECTRON MOTION

In an important group of luminescent materials the transfer of energy to the luminescent center is brought about by the motion of electrons. Many oxides, sulfides, selenides, and tellurides are of this type, and of these zinc sulfide has been most widely studied. It is frequently used as the luminescent material in cathode-ray tubes and electroluminescent lamps.

Electronic processes in insulating materials are described by a band model such as that illustrated in Fig. 8. The electron energy increases vertically, and the horizontal dimension shows position in a crystal. In the shaded area, called the filled band or the valence band, all the energy levels are filled with electrons. No electron can be accelerated or moved to higher energies within this band since the higher levels are already filled. Thus the material is an insulator. Above the valence band is an energy region called the forbidden band, which has no energy levels in it for pure materials. However, imperfections may introduce a local energy level in this region, as illustrated by the short line above 3 in Fig. 8. Above the forbidden band is an energy region called the conduction band. Here there are energy levels, but in an insulator no electrons. If an electron in the filled band absorbs light of sufficiently high energy, it may jump up into the conduction band, as shown in 1 of Fig. 8. The empty position left behind in the filled band, called a hole, has properties which allow it to be described as an electron except that it has a positive charge. Both the electron in the conduction band and the hole in the filled band are free to move and gain energy. As a result, current can flow when a voltage is applied externally. The electron and hole can also diffuse far from their origin and can thus transport energy to a distant luminescent center. See HOLES IN SOLIDS.

A simple luminescent transition is illustrated in Fig. 8. Assume that the impurity level (black dot in the forbidden band) is due to a luminescent center and that there is an electron in the level at the beginning of the process. Transition (1) shows the creation of a free electron and hole due to the absorption of light. The hole migrates to the center (2), and the electron in the impurity level falls into the hole (3), thus destroying it. The free electron now migrates toward the center (4) and falls into it (5), giving off luminescence. The cycle is complete and the center once again has an electron. It

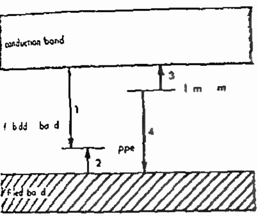


Fig. 9 Energy-band model of luminescence process in zinc sulfide with copper ... activator

important to note that in this process both electrons and holes must be accounted for.

In zinc sulfide the normal activators are monovalent metals such as Ag or Cu. They replace Zn ... To maintain electrical neutrality it is necessary also to incorporate into the lattice ... such as Cl for S or Al for Zn. These additional ... are called coactivators. The ... is quite complex, and is illustrated for ZnS with Cu and Al added in a simplified form in Fig. 9. The ... arrows in the figure show some of the electron transitions that give rise to the luminescence effect. Arrows 1 and 4 show two different luminescence transitions. Arrow 2 shows the excitation ... into the luminescence centre, which may occur by absorption of infrared light by the ... In this case the emission of luminescence is prevented from ... reached. Transition 3 ... of electrons to the ... The electrons may be excited by thermal energy and its appearance may be detected by the appearance of ... This process is called thermoluminescence (see THERMOLUMINESCENCE).

The ... of the ... effect ... makes it difficult to come to firm ... concerning the details of any one system. At the same time the ... makes luminescence ... of ... electronic ... of the ... fields of study. [C.C.K. J.H.S.]

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Luminosity factor

The ratio of luminous flux at a particular wavelength to the corresponding ... radiant flux at that wavelength. It is expressed in lumens per watt. See LUMEN, PHOTOMETRY.

The luminosity factor is often ... in the form of the relative luminosity factor, which is the ratio of ... at the wavelength of maximum luminosity ... The International Commission on Illumination and the International Committee on Weights and Measures have adopted values for relative luminosity factors as a basis for establishment of photometric standards of types differing from the primary standard in spectral distribution of light.

Mathematically the luminosity factor K is found from the equation

$$K = F/I$$

where F is the luminous flux, I is the radiant flux and λ designates the wavelength.

The lumen per watt is also the term used to express the efficiency of an electric lamp which ... should not be confused with luminosity factor. The efficiency is expressed as the ratio of the output in lumens divided by the input in watts. [R.C.P.]

Luminous efficiency

The ratio of the total luminous flux to the total radiant flux. This is generally stated in lumens per watt of radiant flux. Luminous efficiency and luminosity factor are synonymous in the case where energy is radiated at a single wavelength. The theoretic maximum possible luminous efficiency of radiated energy of a source of light comes at a wavelength of 555 millimicrons (at which the human eye is most sensitive) and is 680 lumens per watt based on the C.I.E. photopic luminosity curve, the 1948 International Temperature Scale, and the new value of the candle. See CANDLE, LUMEN, PHOTOMETRY.

The reciprocal of the luminous efficiency of radiant energy is frequently called the mechanical equivalent of light.

The luminous efficiency of radiant energy should not be confused with the efficiency of an electric lamp. Both are given in terms of lumens/watt, but in the first case the watts refer to the total radiant flux, while in the second case the watts refer to the power supplied to the lamp. [R.C.P.]

Luminous energy

The radiant energy in the visible range. In the form of electromagnetic waves, and in the visible region, commonly taken as extending 380–760 millimicrons in wavelength, the luminous energy is ... It is equal to the time integral of the production rate of the luminous flux. See LUMEN HOUR, PHOTOMETRY. [R.C.P.]

Luminous flux

The time rate of flow of light. It is radiant flux in the form of electromagnetic waves which affects the eye ... directly the time rate of flow of radiant energy related according to its capacity to produce visual sensation. The visible spectrum is ordinarily considered to extend from 380 to 760 millimicrons in wavelength; the effective luminous flux is the radiant flux in this region of the electromagnetic spectrum. The unit of measure of luminous flux is the lumen. See LUMEN, PHOTOMETRY.

[R.C.P.]

Luminous intensity

The solid angular luminous flux density in a given direction from a light source. It may be considered as the luminous flux on a small surface normal to the given direction divided by the solid angle (in steradians) which the surface subtends at the source of light. Since the apex of a solid angle is a point, this concept applies exactly only to a point source. The size of the source, however, is often extremely small when compared with the distance from which it is observed, so in practice the luminous flux coming from such a source may be taken as coming from a point. For accuracy the ratio of the diameter of the light source to the measuring distance should be about 1:10, although in practice ratios as large as 1:5 have been used without exceeding the permissible error.

Mathematically, luminous intensity I is

$$I = dF/d\omega$$

where ω is the solid angle through which the flux from the point source is radiated and F is the luminous flux. *See* LUMEN; PHOTOMETRY. [R.C.P.]

Luminous paint

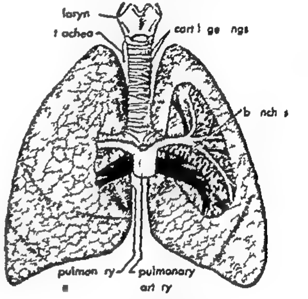
A type of paint that glows in the dark. Luminous paints may be either of the self-luminous type (energized by a radioactive salt) or of the type that requires excitation from an outside energy source such as light. Both types are made by incorporating luminescent material into the paint formulation.

The self-luminous paints glow continuously for several years and are used chiefly for painting the dials of watches or compasses. Zinc sulfide-type phosphors are generally used in their preparation, along with traces of some radioactive salt such as radium bromide or mesothorium bromide. Excitation of the phosphor is principally by bombardment of alpha particles (nuclei of helium atoms) from the radioactive salt or from one of its decay products.

The paints that require an outside source for excitation may be classed as either short-afterglow or long-afterglow paints. The luminescent materials in the short-afterglow (or fluorescent) paints are generally organic polynuclear hydrocarbons like anthracene or chrysene, or various luminescent dyes such as rhodamine. Long-afterglow (or phosphorescent) paints generally employ either alkaline earth sulfide-type phosphors or zinc sulfide-type phosphors. The former type give distinguishable luminescence for periods up to 10 hours, while the useful afterglow of the latter type is generally limited to 1 hour or less. These paints are used, for example, under blackout conditions during wartime. For painted arrows or signs on a wall it is necessary to have an extremely bright afterglow for a relatively short period of time. [C.C.K.; J.H.S.]

Lung

In man, the paired respiratory organs in the chest, separated by the heart and mediastinum. The right lung has three lobes, the left lung, two. A bronchus, an artery, and a vein enter each lung at the hilum; each branches again and again to form lung lobules and smaller divisions. The terminal airways, or bronchioles, expand into small clusters of grapelike air cells, or alveoli. The alveolar walls consist of a single layer of epithelium and collectively present a huge surface. A small network of blood capillaries in the wall of the alveoli afford exchange surfaces for the diffusion of gases.



The human lung. (From T. I. Storer and R. L. Usinger, General Zoology, 3d ed., McGraw-Hill, 1957)

A serous membrane, the pleura, covers each lung and is reflected over the adjacent walls as the pleura.

Lungs are simple sacs in those fish that have them and in reptiles and many amphibians; only birds and mammals have developed the complex warm-blooded respiratory system similar to that of man. *See* LUNG DISORDERS. [E.G.ST.]

Lung disorders

Diseases of the lung include inflammatory processes due to infections, processes of scarring and destruction which reduce the respiratory surface of the lung, disturbances of pulmonary circulation, and tumors. The lung can also be affected secondarily by extension of bronchial diseases (*see* BRONCHIAL DISORDERS). For a general discussion of the effect of pulmonary diseases on the whole organism *see* RESPIRATORY SYSTEM DISORDERS.

INFLAMMATORY DISEASES

These diseases can be acute or run a chronic course; they are usually accompanied by fever.

Pneumonia. This is an acute inflammatory disease of the peripheral air spaces of the lung caused

by infection from ar ous pathogen c microorgan ms. The type of p e m nia is larg ly dete mined by the infect ng agent, which reaches the pulmonary al eoli through the a r ays Pneum nia is a gra e disea e, ma y f rms ha ng a h gh mortal ty rate.

Lobar p umo ia Th s is the c mm e t f rm to h h th t rm p e monia i appl ed without peci ic tion. It is ca sed by the gram po iti e pne mococc s, *Dipl c c us p eum e* Infect n by p umococ i u es p eumo a only if the resistance f the pat ent aga t inf t n is mark edly l ed by uch ditio as chill p found f tigue, sev e inj s many se i us d e ses particularly those ssoci ted with fa lu e f the ght he rt. The i fectio tarts in one ea and p d p dly th ough ut an ent re lobe of the l g. Th fi t de e of ti ue rea ti n is con gesti n f the al eol r cap llar e wl h fill with blood an exudat n f pl ma to the al e li th th bseq nt add t n of leukocytes o white blood ells f llo s. This exudate l ts when fibr f m ti n oc urs. The norm lly pongy lung it ns is firm l rl ke c te y The pleura becom l ed d some ex date w th fil rin n ad the pleu al c ty The le kocytes a e ble t na ti te, allow and de t oy the pne mococ i if they ha bee p evi ly made le s ggre i e by the act f ant bodies, formed i the body r by th py ith s lf n m des or a tib ot s (e PHAGOCYTOSIS) Re t tut n t ke pl e thr ugh liq fa t n f th cl tted xud t and rem al f th fl d by th lymph tic nd blood es l S sto ti u d tr y d the p ti n f the l g ti u is u u lly c mplet ly e t red w tho t a y re id a l are insta s, the exudate is replac d by on necti t u r an bsce f rms

Focal pneum nia B ch p eum ni r focal pn um ni s ca sed by trept c cci st phylococci d p eumoc c *Kleb ll p m n* f e q ently mpli t g oth di ses, es a type f pn m n a h ch ft n loc l b r n fo be l h r h as F edl d r pn um ni D-

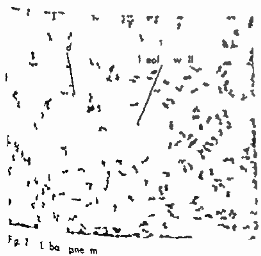


Fig. 1 Lobar pneumonia

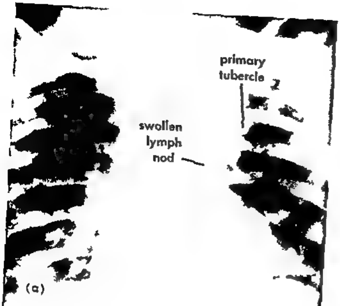
emanating fr m the maller bronchi br ncho pne monia tends to de troy ti ue and to f rm ab ce e Heal g re ult in scarr ng r f rmati n of n encap ulated ca ity The e ases often ha e a high fatality Tl e m rtality rat for Fri dl nder pneumonia wa 80% and despite antibi tic is still al ut 0%

I ter tit l pn um ia This di a e is character i ed by e n e ti n of the al eolar capillaries and a cumulat n f fl d a d leuk cytes in tl e loo e nnecti e tis e f the lu g It i u ually found in infection cau ed by iru r k tt ial rgan ms, or imilar p tl og

Pl risy Pleur y r pl uriti i an inflamm ti n f tl e pleur acc mpan ed by fluid a umulat n in tl e pleural ca iti It occurs n m ny d sea e f the l g p rticularly *in tuber lo* Tl e l lood essels f the pl ura be me cong ted fluid n t ining pr t n and wl ite blood cells e cap s fr m the cap llarie a d a um l tes fir t i the nnec ti e t sue F m there it pa e thr ugh the lining lls f the ple ra int the pl al e where it cc mulat ch fly i the pace between the dia ph agm nd tl e che t w ll F brin d p ted n the pl ural surfa es The ple r l effu i n can be r m ed ith as th rapeutic me re r f r di gn tic p pose by m ting a eedle thr gh tl e he t w ll E min ti n f the fluid r eals p ll b cteri r tum ll p inting to the ti l gy f the pl ur t If th inflamm ti n the fl id i re bsorbed Tl e fibr n ered urf ces f lung a d hest wall tick t g ther n ecti e ti e a d blood l gr w thr ugh th dh i a d bl t rat the pl ur l p ce A m e fl i ca bee me p rul nt in whi h ca e a thi k p le of fibr u t ue f rm bout it Such an cap ulated m f p s i called n empyema.

Pulmo a y t b r ulosis Th s i a inflamm tory dise e of th l g due t nfecti n l y th tul e cle bac ll *Ify b t m t b r ul s* a gram p ti a d f t rod The pathway f r nfect on i lly thr gh the airways. Th primary s te f t l l i i m t c the lu g, whe e a loc l z d nflammat ry nod le f spec fic truc t r tl t ber le f und Th i fect n tra els thr gh the lymph s ls nd r che the regional l mph n de wh ch be me ll n Th s so-call d p m mpl x f t be l n ofte be i b x) (F g 2) Immu ty aga n t th t ber le b ll des l ps gr d lly n m t pe s ns Heal g f the pr mary le n s lea e m ll l ified ar The l ngs agai be ff ct d by ec d a t b cul n th d em n t d m l ry f m with h ndred f mall t b r le r n the l al d a o s f rm in wh ch t ue i pro g e l d i ved so that a tuberc lou a ty ults S TUBERCULOSIS

Scarring and destruction Th n rm l sp nge l k patte f th lung c n be lt red by enl rge ment a i p lm ary mphy ma by c llap e f th r p ce a n tele ta i E t n i e r ng f m h r t t n d t y th pulmo-



Fg 2 T be culos s ( ) P imary (b) P lmo ry

nary structures by formation of strands and foci of connective tissue fil rosis

Emphysema This condition designates two entirely different diseases In inter titial emphysema air bubbles are found in tissue chiefly in loose connective tissue where the air can pread easily It is frequently located in the inter tices of the lung and mediastinum having diffu ed from ruptur d alveoli of the lung Pulmonary emphysema is a state of abnormal distension of th peripheral air spaces of the lung The walls of distended alveoli are thinned finally leaving large spaces con isting of coale cent adjacent groups of alveoli which have lost their epta (Fig 3) These blebs can reach several centimeters in diameter and are then called bullae resulting in bullous emphysema This is due to air trapping in peripheral parts of the airways when air enters the e air spaces on inspiration but is prevented from being expelled during expiration by a val elike mechanism in the small r bronchi In diffuse pulmonary emphy ema a large number of *slightly* disten[ded] air spaces is encountered throughout the lung [It] can occur *when a part* of the lung has either und[er]gone atelectasis or has been removed surgically [A] minor form *is quite* common in older individua[ls] Emphysema patients *uffer from* severe hortn[ess] of breath since many alveolar capillaries have be[en] destroyed *with the* alveolar walls The respirato[ry] surface of the lung *is significantly* reduced and th[e] blood is incompletely oxygenated resulting in cy[a]nosis

Atelectasis In the *adult* lung this condition [is] the collapse of the air spaces through ob tructio[n] of a *bronchus* by tumors foreign bodies or othe[r] conditions The retained air is *absorbed* by th[e] blood Compression of the lung from outside b[y] tumors also leads to atelectasis (Fig 4)

In congenital atelecta is *expan ion* of the lun[g] is partly or completely prevented at birth for vari ous rea ons and *the air* spaces cannot become filled with air Complete congenital atelectasis i[s] *fatal and* accounts for the death of many newborn children

Pneumoconiosis This is a general *term for a* group of diseases of the lung induced by various kinds of dust which results in focal scarring They *mostly* represent occupational disea es ince the exposure to the particular dust has to be exten sive and of long duration The most important agent is silica which is inhaled by miners stone masons *metal* grinders sand blasters and others and which causes silicosis Most of the inhaled du t is coughed up however the particles which reach the alveoli

Fg 3 Pulmo ary emphys ma

are t k n up by phag cyt d dej it d i the te titi l t u f the l ng whe th y u e irrit ti The t e rea ts by f rm ng a c p ul ar d the rr t ting f reign bdy Si e the i r tatio does t e e um r mall f rm d le f rm hi h are scattered th ugh ut the l ng By c les en e f the e n dule la ge a ea f the l i g bec me fib tic fin lly reduc g the b atl ng pa ty gn fi tly a d res lt g in h t e f br th T be l i i f qu tly a c t d with ilicosis.

CIRCULATORY FACTORS

D se ses f the latt pa t ul ly l art diseases, h e the fl e n p lm nary ircu l ti d h e on tl l ng Th re p rat ry f c m t ffect ly di t rbed ften w th a ud den unexpected nset S CIRCULATION DISORDER

Pulmonary edema Th an cum lat n f bod fl d th l g Se m e c p f m th c pillaries mul tes fi t in the lo e c nect e ti e f th al eolar wall d then p e t th pa es d d pla s the air The flu d nt n ing p t in m ed w th fi e ai b bbles a a re lt f esp t n and f rm fr th whi h gr d lly p hed i to the l r nch d can ppea th m th. Lo d b bbl g s he d resp a ti n. The p t t h w h rt e f bre th and cy ti h t lly d w g in l ow fl d (Fg 5)

P lm ry ed m ca b c d by loc l p oc esses h h r a e the perm b l ty f th pil laries f r fl d Th s th flamm t h s p m a, nd po so g by t xi g partı ul ly ch ar g e ph g Th m t mm e f p lm ry dema i a p ll ry blood p es e, h ch ctually q the fl d t f th es l Th oc wh n th l t h art fail t f lfill t f nct whi l tl e ght h art ha ret d m les rm l ffi e cy T mpo arily m e blood p mp d t the l g th n s d ai ed t, e lt g e g g me t f th pulm ry e d p ll r e d p f fl d t the l lt Th ea d l p y r p dl Th m t ff ti e t tme t f th typ f p lm n ry d m t ll e ts f p nct re f

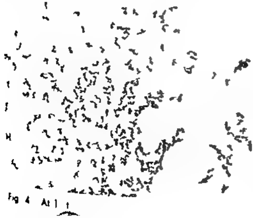


Fig 4 At l t

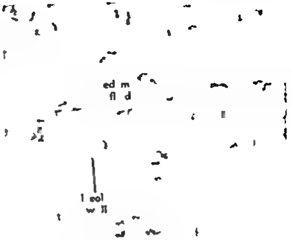


Fig 5 P lm ry ed m

ein w tl letti g f bl d t redu e tl lt f l l d p mped t tl l ng

Pulmonary infarct Tl i re fl in a destr ti n f a p rti n f th l ng d t the dd n l f a b h f th p lm nary t ry by l dg ment f thr mb s. Thr mbi lly f rm in a ften i r f tl e tl gl nd e el sed d di pl d by tl e l l d tr m t th p lmo n r rtery wl e they ic l d m ll r l ranch Death f t e oc u ly if the l ng alre dy d maged by th r di e e g t d edem b failur of tl l ft he rt Ti ecr i pre nted he lthy lu g l y tl ll t l l l d upply fr m the b hial art rie An infar t i wedge h ped a rd g t tl d t l l t n f tl b he f tl oc l ded e el It has a firm d k ed ppe r e, d t bl ed g t th ti ue Patient w th large i f t lt n mb wh le malle inf t h l by sca ring

Tumors of the lung I m ry t m f the lu g a e m tly l ated in th l nchi and lud b nch l d ma a d br nch g in ma The lin g ll f the al eoli g e ri e t pri m r al l ll a m wh h i r l ti ely e. Tum f the pl mesoth l m ta gr w t the lu g ti u

The l g i f equently the prim y te f me t t f m t m rs of oth r g ns wh e lus t f er cell penetr t t th i d r arr ed way by tl e bl od t eam wh ch b ing th m i t the l g S e tl y e t b g t pa th gh the l eol r cap ll th y e h ld b ck d c t ue th r be t gr wth f rm g w tum wh h de tr y th l g ti [E WE]

B bl g phy S RESPIRATO Y SYSTEM DISORD RS

Lungfish

A m mb f th p der D p The l ng fi he w f rm ly b d t a d the e e m f l f rm d t g f b ck th D i Th y w l m t d t th g era h w ll l t d f m t l t The mbl dd r l g l ke a d d l y p at y d e,

with or without gills which are also present The lungfishes are slender elongated fishes The premaxillae and maxillae are lacking and the teeth are specialized into crushing structures called triturial plates

Neoceratodus forsteri the Australian lungfish is the heaviest bodied of the three It has large cycloid scales sturdy short paired fins and a relatively deep body It now occurs only in the Burnett and Mary Rivers of Queensland This fish uses its lung as an aid to breathing in stagnant water It does not estivate

Lepidosiren a monospecific genus of South America and *Protopterus* of Central Africa are similar They have slender bodies small scales and long very slender paired fins They live in seasonal swamps and move about over the bottom hunting mollusks during the wet season breathing primarily if not entirely by means of their gills During the dry season they form a mucus lined cocoon in the mud in which they estivate During this period respiration appears to be entirely through the lungs They escape from the cocoon and resume activity with the return of the wet season There are three species of *Protopterus* See DIPNOI

[J D B]

Lupine

A cool sea on legume bearing digitate leaves with five or more straplike leaflets and having terminal racemes of pea shaped blossoms

Three species the blue yellow and white named for the color of their blossoms are used in field planting Lupines need much less potash and lime for growth than the clovers They do not tolerate extremely low or high temperatures and are attacked by numerous diseases and by several insects

The older varieties of lupine contained a bitter toxic alkaloid and were used only as cover crops However since 1912 European plant breeders have selected low alkaloid varieties of blue and yellow lupines which can also be used for forage

The production of blue lupine as a cover crop increased greatly in the southeastern United States beginning in 1939 Since 1951 however lupine culture has declined partly as a result of an increase of disease and insect injury See BREEDING (PLANT) COVER CROPS LEGUME FORAGES [P T]

Lupus erythematosus

One of the collagen diseases in which connective tissues show a similar form of biochemical and structural alteration Each of the collagen diseases is a distinct clinical and pathologic entity and such a grouping exists more as a matter of convenience than because of a common etiologic factor See CONNECTIVE TISSUE

Collagen diseases display three local forms of degeneration inflammation namely fibrinoid mucoid and hyaline degeneration Each has its own histologic appearance and may occasionally be seen in other diseases The causes are poorly understood but hypersensitivity and nucleoprotein derangement appear to be involved See HYPERSENSITIVITY NUCLEOPROTEIN

Lupus erythematosus is an acute or subacute febrile disease that may produce widespread damage to the connective tissue components of many organs and tissues It occurs predominately in young women but males appear to be increasingly affected perhaps because of development of better diagnostic procedures The blood vessels heart kidneys skin and serous membranes are characteristically involved One of the most striking findings in more than half the cases is the appearance of a reddish butterfly shaped rash over the cheeks and nose (see illustration) A blood serum factor is present in lupus which produces almost pathognomonic changes in the blood neutrophiles

There is a significant incidence of involvement of the heart (myocarditis) and also of the lining and valves of the heart (endocarditis) Kidney lesions (nephritis) and lesions of the serous membranes of the heart (pericarditis) lungs (pleuritis) and ab

(a) (b)

Lupine (a) Plants (b) A field of lupine in flower

pus ryth m t (W A N D I d Am
d strat d Med J D ct y 19th d S d s
1942)

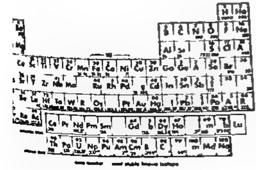
domi al perit ne m (p rito t) are commonly enco tered Small arter s bec me the ite f r n flamm tory rea tio s, e pe i lly m the k dn y

Th clinical p ture is q ite ar ed dej e di g th rgan n l ed A ir egul r fever i m st char t t c, d the patie t mo e ill than the ph al fi d g ld i d c te W akne w ight loss, m tal aberr t on a d k dn y or he rt c m pli ti ns omm n Lup s ften mimi s th r dise ses bec e of the w de p ibility f ti u dam ge. De th ually e w th n 2 5 years fter an intermitt t ill ess ma ked by c se and p gressi e dete ti

D c d l p s s common kin di a e that el d m p ecedes di em at d lup s m ny a th i ties d the t to b ep rat di a s u ly Oth r coll g di ea es clud p ri rte-tis nodosa, dermat my it a d le od rma Rh um tic fev he m t id rth tis, a d rum ncks s, as well s c rta n th r d seases may b incl d d in th t g ry Ea h of the d sord rs ha is n pecul arit s, l cal c se, d pr gn See RHEUMATIC FEVER [E G S T]

Lutetium

Eleme t umber 71 I t t m Lu m ry e il and the hea t membe f th r e- rth p Its at m e ght i 174 99 d the tu y occurring el m t s m de up f th t bl



sot pes L 97 41% a d L 2 59% It w d sc red n 1906 by G U bai who n med t l tec m, ft t n m f P It w lso disco ed d p d tly by C. F A r Welsbach wh named the element cassiopeium but lutetium is the accepted form at pre ent The salts are colorless and give a tri alent ion in solu tion For the propert es of the metal see RARE EARTH ELEMENTS [F H SP]

Lux

The u it of illuminati n when the square meter is taken as the unit of area It is defined as the il lumi ati n on a surface ne q are meter in area n which there is a l minous flux of 1 lumen uni f rmly di tr b ted r the illum nati n n a surface all points of which are at a di t nce f 1 met r fr m a unif rm p nt urce f 1 candle See ILLUMINATION LUMEN [R C P]

Lychee

The pl nt, *Litchi chi ensis* also called l tchi is a memb r of the so pberry fam ly (Sapindac ae) and nat e f so thern Chi a where it h s been lti ated f more than 000 years It i n w bei g g wn suc e fully n India Uni n of South Afr ca Ha a i Bu m Madagascar We t Ind s Brazil H nd r s Japan A stral a a d the so thern Un ted States The f uit is a e- eeded b rry The th n le th ry ugh hell pericа p f the r pe fru t i bright red in l r in mo t rieties Be-n ath the h ll a d ompletely ur u di g the eed the ed ble a il or pulp The fr it may be at n fresh ca ned r dr ed In Ch na the fr h f uit i c n d ed a gr at del ca y See SAPINDALES [P D S]

Lychniscosa

An rder f the ubcl s He a terophor in the l He a t n llid The p en hymal megascleres f th se p g a e ted t f rm a rig d fr me-w k Th p ren hymal m ga le a e all r in pa t ly hn c hexa tin in wh h the c tral p rt f the pi le is s rou ded by a ystem f 12 trut E ampl f th rder are *Aulocyst s* nd *D tylo ly* See HEXACTINELLIDA HEXASTEROPHORA [W D H]

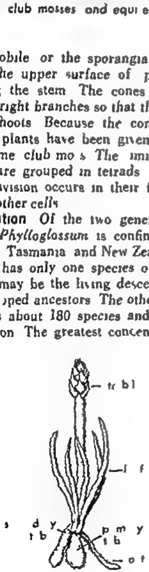
Lycopodiales

An d r f th pl t bphyl m Ly p ida with a f il hi t ry t d g back to the P l zo c (e GEOLOGY PALEOBOTANY) These plants c m m nly ll d l b m se att d th r greatest d l pme t du ng the Carb f rous period a d n l ded e e l tre l ke f rms mp bl in size w th the p s t d y p (F g 1) T day the d t ns nly tw *Ly p dium* and *Phyll gl s m* comp ed f sm ll herbaceous e g n pla w th up ght t ailing tems b r g m s mall mple p rally arranged l S me f th p al sp es are p phytes (li e p rch d la g r pl t) The stem are d h tomo ly b a h d (f ked) In s m es o e fo k f rm a l t r l b nch wh l th th be-m the ma Th phyll (po gi m be ng l a) m y be ggregated together int

Fg 1 Re torat o of Carbon fe ous forest trees an ce tral fe m club mosses and equi etum (F om E N Transea H C Sampson and L H T ffa y Textb ok of Botany re ed Harpe 1953)

cone or strobile or the sporangia may be borne singly on the upper surface of porophylls scat tered along the stem The cones are often ele vated on upright branches so that they occur abo e the leafy shoots Because the cones resemble a club these plants have been given the erroneous ommon name club mo s The imilar spores (ho mo pores) are grouped in tetrads indicating that reduction division occurs in their formation from the spore mother cells

Classification Of the two genera included in this order *Phylloglossum* is confined to portions of Australia Tasmania and New Zealand (Fig 2) This genus has only one species of simple struc ture which may be the living descendant of more highly devel ped ancestors The other genus *Lyco podium* has about 180 species and is world wide in distribution The greatest concentration of spe cies is in the tropics and subtropics but the e plants al o grow in the arctic region Many of the species are perennial and inhabit the moi t wood land or forest floor whereas others are epiphytic and grow upon fore t trees

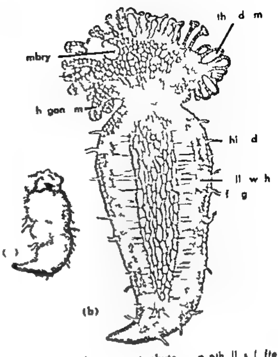


Fg 2 Fert l plant of *Phylloglos m* d mmo d i twice natural s ze (Fr m A W H upt Plant M ph l ogy McGraw H ll 1953)

Structure In most re pects the anatomy of *Lycopodium* especially that of the roots and leaves is like that of other vascular (higher) plants *See* LEAF (BOTANY) ROOT (BOTANY) STEM (BOTANY) The primitive arrangement of the vascular tissues in the stem is called a protostele (a olid cylinder devoid of pith) which may be modified by the relative position and amounts of xylem and phloem in the mature stem (*see* PHLOEM XYLEM) All of the va cular tissue is primary ince it is produced by a cluster of apical meristematic cells with no indication of cambial or secondary activity (*see* MERISTEM APICAL) Development and maturation of the xylem is exarch or toward the center A strand of conducting tissue extends from the stele int each leaf and becomes its vein but no leaf gap is produced where the strand emerges from the stele Similarly each branch and root is connected with th primary tele but in the e case gaps are left in the central cylind r as is true in all va cular plant

Alternation of generations The conspicu us plant with its root stem lea s and sp rangia is the sporophyte r pore producing generation (Fig 3) The sporophyte begins with the yg te (fertilized egg) and ends with the formation of spore The gamet phyte (gamete r du ng gen eratio n) begins with the pore and nd with the union of the egg and erm in the f rm ti n f th zygote In *Lycopo lium* porangia are large and somewhat kidney haped and are borne ingly in

the upper leaf xils. Each sporang um h s a l o t talk and a th k all of e r l cell lay r Wl n mature, t co tai s a m s of mall yellow thi k alled po es. The pores are l berat d thr gh a u ns rse sl t appeari g n the p a g um wall In this ge s the e is a se es f p ogre t tage am g the m r u peci aryi g fr m tl e t hich every leaf the plant is pote t ally a poro-ph ll t th se n wh ch th sporopl yll are agg e gated into mpact ell d ff r nti ted trobili (co es) Acc rd ng t spe ies, the l b r ted p r s ary in th peed w th wh h they ge min te nd d l p t g m tophyte (gamete pr du i g gen u) Many po seemi gly equ re tl e pr s-ence of my orrh zal f gu f r the r co t n d ex -ence and mat ratu n (s e FUNGI) In some pe-ies the gam t phyte grow abo e gr u d a d be-come green, hereas ther pe t tl ey de el p bel ground and a e de o d of chl r pl yll The gamet phyte may be ther t be o r br l It the bte anean types wh h ar fe ted with f gus and r prophyti (l e n d ad o g tter) The se o g s (nther d d arche-g ia) a e l g a d are borne n the t p u fa f th gamet phyte (Fig. 4) Fr m a p rfi ial cell, h ther d m d el p t a o al m f pe m m ther cells wh h p tr de l ghtl l the m ss f g met phyti tt e Th pe m pro-d ed n th anth d um a e f if rm (pi dl haped) d e h ha tw fl g ll attached at th



Fg 4 Ly p d m g m t phyte p oth ll s (lle g hm) ( ) Ext l w f l mpy bt g m t phyt (b) L g t d l ct f g m t phyte sh w g h g d th d mbedd d th t p p rt h d o g t th f d c ll t g f g (d k ll) (F m H J F ll d O Tpp C ll g B t y H lt d 1954)

a te r nd The a h g ia (fem l) re pro-d ed th sam th ll b t ally t w rd the m g s M ny h g n are f rmed b t ly a few d el p aft r f rt l zat In some spe ie e r l n w po phyt may be prod ed f m the ame tl all at nt ev l er ever l ye r Th gamet phyti tl ll p r t nd u pplie tri t t th de l pi g p phyt which ent lly be m nt ely self upp ting Th wl l pr f po phyt d el pm nt e y low a d t m t ke ral ye f r th y ung plant t re ch th rf f the tl a d t k the f tur s f th m t pl nt S TRACHEOPHYTA [P A V] *B bl g phy S* LYCO SIDA

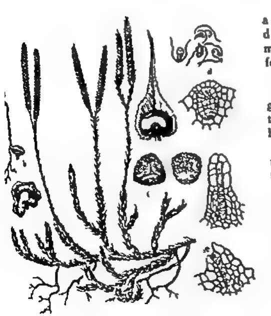


Fig 3 Ly p d m l t m ( ) Old p th ll (b) P th ll w h y g pl t tt h d ( ) A th d rt l ct (d) Sp m t d ( ) Y g ch gon m th k t ll l d (f) Op he-gon dy f f rtl t (g) Pl t b g (h) Spo phyll w h p d p g m ( ) Sp f tw p t (Aft B hm f m E St b g F N ll H S h k G K t A T tb k f B y 3d d. M m ll 1908)

Lycopodineae

The ly l f th bphyl m Ly p da It mad p f th o d rs t g the Ly o-pod l cl b m the S lag llales m ll l b m ses the Lep d de d ales g ant cl m (f d ly f l) Pleu m l (f d nly f l) a d th l et le ll w rt Th l g de f th l ss f g that th t dy f the r t t r d l f le p d l t the u d ta d ng f the n w t t p s f p ra a d th me h ng wh h h ed du g the l t n f th p t l d fl (ee PALEOBOT Y)

Th tw mo t mm n g a d the h g th w d t d t b t e *Ly p d m* nd

Selaginella. In *Lycopodium* the spores produced by the sporophyte are all alike (homospores), whereas in *Selaginella* the spores are unlike (heterospores). See ISOETALES; LEPIDODENDRALES; LYCOPODIALES; PLEUROMEIALES; SELAGINELLALES; TRACHEOPHYTA. [P.A.V.]

Bibliography. See LYCOPSIDA.

Lycopsida

A subphylum of the plant phylum Tracheophyta having a long fossil history but today restricted to four living genera. The living members, commonly called club mosses (a misnomer), are of significance in that the study of their structures and life cycles provides clues to the understanding of the many extinct species. Some of these plants, now known only as fossils, were the dominant species of the extensive swampy forests of the Carboniferous and grew to 30 meters in height (see GEOLOGY; LEPIDODENDRALES; PALEOBOTANY; PLEUROMEIALES).

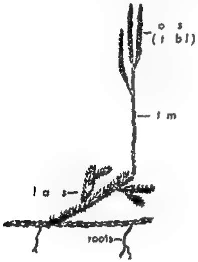


Fig. 1. Lycopodium, or club moss, showing prostrate stem with many small leaves, upright stem bearing cones or strobili, and roots arising from rhizome. (From H. J. Fuller, The Plant World, rev. ed., Holt, 1951)

Fig. 2. Phylloglossum, with fleshy tubers at base giving rise to roots, quill-like leaves, and a stalk with a terminal cone. (From H. J. Fuller and O. Tippo, College Botany, rev. ed., Holt, 1954)

Fig. 3. Selaginella kraussiana, portion of a sporophyte. (From G. M. Smith, Cryptogamic Botany, vol. 2, 2d ed., McGraw-Hill, 1955)

Classification. The living members of this subphylum are confined to the four genera *Lycopodium*, *Phylloglossum*, *Selaginella*, and *Isoetes*. They are herbaceous plants growing close to the ground or as small epiphytes. All are widely distributed except *Phylloglossum*, which is confined to portions of Australia, New Zealand, and Tasmania. The greatest number of species are to be found in the tropical zone, although some species of *Lycopodium* may be found in the arctic regions. Nearly all of the genera grow in moist, shady habitats.

Structure. The living Lycopsida are characterized by a dominant independent (self-sustaining) sporophyte which is differentiated into a root, stem, and leaves. The stems and roots branch dichotomously (fork). The leaves are small, simple, and spirally arranged. See LEAF (BOTANY). Typically they have but one vascular bundle, which produces no leaf gap as it departs from the stele of the stem. See STELE; STEM (BOTANY); VASCULAR BUNDLES. The vascular tissue of the stem is usually a protostele consisting of a solid central core of xylem surrounded by a cylinder of phloem, although some lycopods have the center of the stele composed of parenchyma (pith) rather than tracheids, an organization termed a siphonostele (see PARENCHYMA; PHLOEM; XYLEM). The phloem is surrounded by a pericycle and a well-defined cortex and epidermis (see CORTEX (PLANT); EPIDERMIS (PLANT); PERICYCLE). The tracheids found in the vascular tissue are largely scalariform. Several species have a cambium which forms secondary

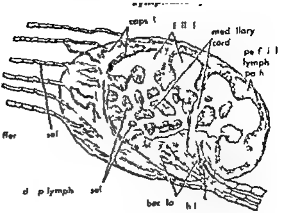
g. 4. hoot s tt ll n t l se (F m A W pl Pl t M ph l gy M G w-H ll 1953)

scular ti ue (see MERISTEM LATERAL) The spo- ›angia (por p od ıng stru tures) re s l tary on the upper fac of fertile le es c lled sporo- ph lls. The po ophyll may be l calized at the tıp of a branch and f rm a tru ture called cone or str bil s. The e ıs a te den y fo the sm ll ■ me- t phyte (gamete-p oducing generat n) to be apro- phytic (li ing o dead rga c matter) The sp rm p od ced ın the anth idium re bifl gellate and motile. Se I OETALES LYCOPODIALES LYCOPODI EAE SELAGI ELLALES TRACHEOPHYTA [P.A ¥]

Bibliog phy H C. Bold M phology f Pla ts 19 7 H J Fuller nd O T ppo Colleg Bot y rev ed 19 4 A W Haupt Plant Mo phology 1953 G M Smith, Crypt gam c Bot ny v 1 2, 2d ed., 1955

Lymph node

Aggreg ti of lympho d ti s e fo nd alo g the co se of lymph tic e el Th y y n l gth f om 1 mm t 2 cm or mo e, a d n hape f om sphero l to fl tten d n rr m e sides A fi b a le urr d each gl d d e ds p- p rting she t t be ul e through th lymph d tis e. Th lympho d tis u s c mp sed f g rm n l t f lymphocyte t g th w th the cells, parti l rly tho e f the r ti l ■ dothelial tem. Lymph glands r f d n s p fici l nd deep sit s, including th e k ax lla, g ■ med astinum, abd m pelvis, nd nte t l wall (Pey p hes) At l ast t f ti ns re pp e t to upply lymph t the c l ti n and to ■ mo e b cteria I t m tter carr d t the



D g am f lymph node (Afte C Toldt A Atlas of Human A tomy F Stude ■ a d Physic ol 1 2d d M m ll 1941)

node by the lymph t c els. In additi n it t th ught that lymph gla ds m y be the ıte of anti body f rm ti ■ S e ANTIBODY LYMPHATIC SYS- TEM [E.C ST]

Lymphatic system

A system of ves els ın the vertebrate body begin ning ı a netwo k of exceedingly th ■ walled cap- illar es ı alm t all the organs and tiss es exc pt the b ın nd bones. This network ıs drained by larger hannels, mo tly cour ng lo g the eins and entu lly joı ng to f rm a large e el the th racic duct, wh ch run beside the spı l c lumn to enter the left subcla ian eın at the ba e f the ne k The lymph flu d rıg nat s ı the ti sue p ■ by filt ation from the blood capillaries While ın the lymphat c capillar es ıt ıs cle r nd watery At ı tervals, h we er long the larger lymphatic es- sels the lymph passe through pongelike lymph node wher ıt recei ■ great numbers of cells, the lymph cytes, and becomes turbid The lymphatic essel other than capillaries co ■ ■ numero s al es ■ e enting back flow of the lymph The function of the lymph tic syst m are to remo e particulat materials such s molec lar proteins and bacteria from the tis ue to transp rt fat from the intest nes to the blood and to supply the blood with lymphocyte

Th s artı le conta ns sections n th embryology f the lymphatic system and spleen and the om par ■ e n tomy histology and phy iol gy f th lymphatic sy tem

EMBRYOLOGY

The m de f d elopment f th vas ular system ın c nt ad t nction ■ the arte ı l nd ve o s sys- tem ha b n lu d ted nly nc ab ut 1910 Emb y s f repr se tati pe ıes f m ll cla s of rt ■ ate ha e been tud ed nd s y t th re s n gre m t n fu damental q esti ns pert n ng t th e ly embryol gy of th s el ı y t m The n l d tatus ppe rs to re t m ■ n d ffi nce of terp t t ons th n n ■ uffic e t ob rv tion d f ct

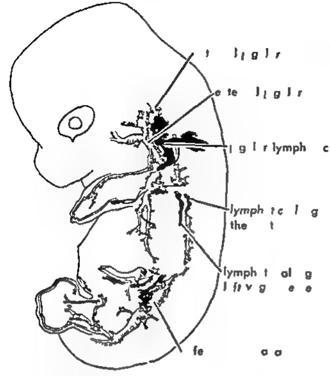


Fig. 1. Lymphatic vessels and veins in a 14.5 mm rabbit embryo. (R. O. Greep, ed., Histology, Blakiston–McGraw-Hill, 1954)

A sharp distinction must be made between the processes of the earliest formation of discrete lymph vessels and those leading merely to an extension of once established channels. The former entail actual genesis of endothelium (vasculogenesis); the latter merely represent growth. Growth by budding and branching of newly established vessels occurs throughout the vascular system, whether hemal (arterial and venous) or lymphatic. The controversial aspects mainly concern the earliest beginnings of lymph vessels.

Theories. There are two conflicting concepts. One is that all lymph channels develop by centrifugal outgrowth from embryonic veins, specifically from their endothelial lining. In the neck and loin regions as well as in the posterior abdominal wall and at the root of the intestinal mesentery, such outgrowths form saclike expansions (Fig. 1). These are, respectively, the jugular and iliac (lumbar) lymph sacs, the future cisterna chyli (pool of chyle near the base of the abdominal aorta), and the mesenteric lymph sac. All the body-pervading lymphatics are said to be formed by sprouting from these sacs and thus to be derived indirectly from the lining epithelium of blood vessels. The original points of budding from certain veins (cardinals, for instance) either could be retained or lost and secondary evacuation taps for the lymph could be established.

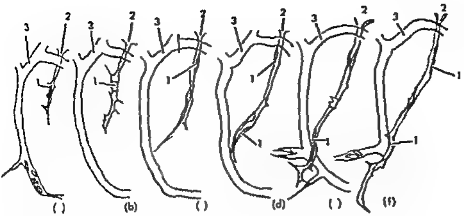
The opposing view holds that the lymphatics arise directly from mesenchymal spaces either adjacent to decadent venules or unassociated with veins. During early embryonic development some rich and temporary venous plexuses become reorganized. Certain venules atrophy and disappear, particularly in regions of the developing lymph sacs. The drainage function is taken over by a lymphatic network which temporarily may carry blood cells received either from degenerative venules or from blood islands in the surrounding mesenchyme. The ultimate connection with major stem veins is always secondary. The system arises in a discontinuous manner and independently of the endothelium of veins. The over-all direction of its development is centripetal. The isolated and discrete spaces converge and fuse to form continuous lymphatic trunks and networks. The main connection of the jugular lymph sacs with the venous system develops early, before the more distal lymphatic primordia have interconnected or joined the sacs. This link between two drainage systems, lymphatic and venous, occurs near the base of the neck (Fig. 1) at the jugulosubclavian junction.

Investigative methods. There are two general methods for the investigation of lymphatic genesis; each has serious limitations. They consist either of the study of serial sections of well-preserved embryos or of injections of the developing lymphatics (Fig. 2). Crucial events in that development take place very early in human embryos, for instance, when they measure only 10 mm. Obviously, it is impossible to detect discontinuous segments of developing lymphatics by the injection method. Serial sections, on the other hand, can be obtained of uninjected as well as of injected embryos. This method in its turn presents difficulties in regard to fixation effects, shrinkage of the delicate embryonic tissues, and interpretive errors in reconstruction. Further progress may depend on newly devised methods.

The latest evidence strongly supports the centripetal view of the origin of the lymphatic system. According to this view the very first beginnings are identical with those of the arterial and venous components of the vascular system. All vasculogenesis appears to occur through the same fundamental transformation of mesenchymal cells into endothelial cells. The lymphatic precursor stages preceding the development of veins are as a rule less distinct, evanescent, and therefore difficult to recognize. This has caused differing interpretation.

Embryonic phase. In human embryos of about 1 in. (20–30 mm) a connected primitive lymph system is already established. The main lymph channel ascending through the thorax in front of the vertebral column (thoracic duct) has joined the jugular lymph sac. At its distal end it is continuous with the cisterna chyli into which converge the lymphatics from the intestinal tract and those of the lower trunk and limbs. The jugular lymph sacs also receive lymphatic drainage from the developing upper limbs through the primitive ulnar lymphatics. Other lymph trunks develop in the head and neck regions so that the jugular lymph sacs soon receive returning tissue fluids from all body regions. Lymph thereby is returned to the economy of the blood vascular system.

In early stages the thoracic ducts are paired and symmetrically developed. Some animals retain du-



(1) ucl f lymph I (2) lymph I (3) blood sel

Fig. 2. S si t g ( )-(f) th g wth of o h lymph t sel the t l f t dp le d g 72 (R O G p d H st l gy Bl k st n—M G w H ll 1954)

ll thor cic ducts. In m y m mmal d m the tho c c d ct sy tem bec mes a yn m tr al thr gh th f rmat o f i terconne ti g li k a d tr phy f rtain segm ts H nc f tl l mph d ai g fr m th l r body reg s cc rs thro gh a si gle m in tr k whi h t m at at the l ft j gul bel an ju ct n

Fetal phase Dur g rly f t l m nth the mai l mph tru k a w ll as the p ph ral lymph sels become pr d d w th l e wh ch ar se e rli in lymphat m l tha i v n Th ir truct) rr ng ment e ha s nt ip tal fl w f l mph By th fifth m th al e are prese t thr gh t the y tem (F g 3)

By gro th f e ti e ti u t a ds th lymph sa bec me tran f med to a l cy plexu or fenestrated tru t e l the m hes betwee the r mai g lymph sp s th me n hym l c ll p lif r t pidly Bl d cap ll s pers d th t bridge nd imm t re lympho yt ppear gre t n mb The h le p e e t th b gi ning of a lymph node (F g 4) Tr n lympl ocyte f rtl er nfli ate the t uctu e a d j r du e c m t ell lar ma ur unded l y lymp l e sel Tl mpl x m y bec m ul di ided t f m gr up f m ller lymph n de B the middle f fetal life tl e di g lymph el f rm cl ara ter t p phe l nu and an in e ting p le i f m d b the adj e t c ect e t The full diff e t at o of lymph node s ttai ed nly after b th

Fig 3 V l lymph l (C rt y G l

SPLEEN

Th i th large t l mph d t i r in rte br te The so r e mat ial for the de l pm nt f th ple n i spl nch i (i er l) me de m n the d r l me e t ry f th embry c st m ch (do al me g trium) Th pl n arises in hum n embry s ab t 10 mm in l ngth s an nc n p cu thi ken ng n th l ft de f that s pen ory f ld f the t m ch A a r ult f r p la ell p l f r ti th tl k i g l c me n d la The b da betwe n the ing pitheli m a d th nd lying m e hym s often nd t nct he the pe fi tr but of e ch rem in n d bt The b n of th n lifer t n re g ow le ap dly a d ult mat ly be mes the ecti g fold b twe n the st ma h nd the ple n (g tro- pl l g me t)

ll e th f lly d el ped sple n n nt r a l ted in the bl d t e m (filt ring bl od rather than lymph) t bec m pervaded by bl od pil l e e ly de el pme t The st m es els are th f tur sple c rt y nd ein

The d el pme t f f rthe tr ct ral d t ils i low B twee th th nd ighth week of hum n d l pme t (15– 4-mm emb y s) the pl en pr m d m is t ll m ely a densely p cked ma of ell lt ppr ches it typ l f rm d n g th thi d m th Th fi t o p c ter ellular n pp ar nd d fi ite ell ds f r t c lar ell b g n t form a netw k N mer u fr ll l b twe n th me he Other ell a r g them el e c c t i ally r d the blood s ls

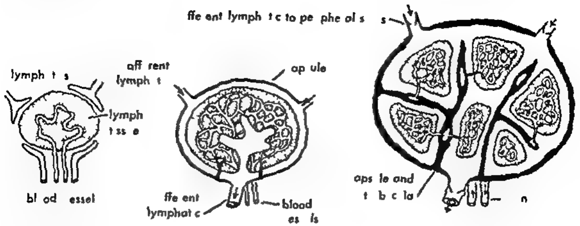


Fig 4 Development of a lymphatic gland (L B Arey and R L Rea Developmental Anatomy 6th ed Saunders 1954)

In the fourth and fifth fetal months the lymphoid cells appear and almost synchronously many pre cursor stages of future red blood cells appear This blood forming function is called erythropoiesis It is temporary in human embryos but fairly con tinuous in the fifth and sixth fetal months During that time the meshes of the reticular background con tain many immature and mature erythrocytes (red pulp) Later the production of lymphoid elements predominates Gradually a white or lymphoid pulp develops Lymphocytes are being produced mainly in areas surrounding the specially shaped sheath (arteries with thickened walls) Full development of the white pulp with lymph follicles and germinal centers is protracted until after birth There are no lymphatic afferents to the spleen although the later developmental features of the spleen resemble those of lymph nodes Some forms of white blood cells are produced in the spleen throughout life and used up red blood cells are being continuously de stroyed in it [A A Z]

COMPARATIVE ANATOMY

Invertebrates It is disputable how far down in the animal series lymphoid tissue is found Some authors speak of lymphocytic cells in annelid worms in mollusks and in other invertebrates

In general the more primitive and less differen tiated blood cells resemble more closely the lym phocytes of vertebrates This is true also of the lower chordates in which so called lymphocytes of the tunicates are said to differentiate into any of the other cell types of the body Lymph nodules are described in some species of tunicates in the body wall and in the gut wall

In the nonchordates it is difficult or impossible to make a distinction between blood vessels and lymphatic vessels Probably the two systems had a common type of origin

In *Amphioxus* however among the lower chor dates lymphatic vessels can be identified surround ing the blood vessels and are seen also around the central nervous system in the dorsal fin and in the metapleural folds

The lymphatics of vertebrates are distributed in somewhat the same manner as are the veins (Fig 5) Thus they are divided into a deep and a super ficial set The deep set develops in relation to the cardinal veins and then makes connection with them and with the superficial set See LYMPH NODE

Fishes In fishes the lymphatic system varies in degree of development in different species In some the veins seem to carry on the function of lymphatic drainage but in a number of species of ganoids teleosts and elasmobranchs a well devel oped lymphatic system is seen The lymphatic ves sels surround the veins in the elasmobranchs in other fishes they are not so closely related to the blood vessels In the elasmobranchs also there may be one or two large trunks which run parallel with the aorta and are comparable to the thoracic duct or ducts of man and other mammals Pulsating or gans called lymph hearts which assist in driving the lymph along the vessels occur in some fishes (Fig 6) The lymph vessels lack valves Lymph nodes are absent although there are collections of lymphoid tissue chiefly close to mucosal surfaces Nodules are found in these collections but they lack germinal centers

The organ of Leydig of the selachian fishes con sists of two large accumulations of lymphoid tissue which run longitudinally the whole length of the esophagus and even extend into the stomach Al though the cells of this organ are primarily lym phocytic they apparently serve as stem cells for all the types of white blood corpuscles in the e fi hes and hence the tissue perhaps should be spoken of as lymphomyeloid indicating its hematopoietic as well as lymphoid character See GLAND

In the sturgeon a mass of lymphoid tis ue has been described which occurs near the heart and resembles a lymph node but its homol gies are doubtful

Amphibia In the Amphibia the lymph tic s tem often includes ery large subc itane u sinu probably to protect again t the danger of l of moisture Dilatations of the lymphatics or lymph sacs occur frequently Lymph hearts are c mm n

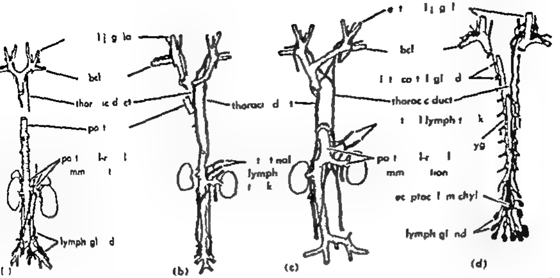


Fig 5. D g m ll t t g th ch f lymph t c tru ks d th t t t the m mm l V tral ws. ( ) So th Am c m key (b) M m- l (lep s) wh h p t I- l c mm c t o re t g ( ) Mamm l g e) (d) Mo (po t m d kid ys t h w) I ll m mm l lymph ters th t th p t f j ct b twe the j g l o d th bcl s. In m t m mm l th l omm t b tw e the lymph sel d th p t l d of s. In m th ght th d ct d ge r t p rt d th ly c m- m at w th e s t the o t f the jug l (H V N I d H W R d Cho date A t my Bl k st n–M G aw-H ll 1939)

in n us parts of th body nd a thor cic d ct s present. A cum l tio s of lympho d tissue a e f ten p esent dj c t to the lymph sacs but ar n t compar ble in archite tu e to the lymph nodes f higher n b tes They may ho e er repre ent an early tage in the de el pme t f h n de

Reptiles. R ptil s h e well-de eloped lym phatic y t m b t la k the pec l features ee i amphibi ns. I the o diles tr e lymph node ha e b en describ d i the me e tery

Birds l the l mphatic system f b rds, lymph odes are w ll develop d in some spec e and h not been dem nst ted n the s They are defi nit ly p ent in ducks, both w ld and d m st c n

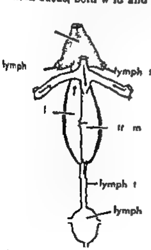


Fig 6 Ly ph h rt t l f t l t (G C K l C p t A my f th V rt b t Bl k st n– McG -Hill 19

gee e and in w ns The locati ns re the c rv cal ers othora i and lumbar reg ns

The ar hite ture of lymph nodes of birds is sim ple th n in m mmal I b ds they ari e by dif ferent ti n with n the walls f lymph tic ve el wher a in mammals they ar e n th surr und g ti sue Th lymph id ti ue of birds c ntain l ght areas in the od les the s called germinal center whe e mit oc ur These centers in bird how e er u ually r more abundant ne r the l rge st u occupy th c ntral p rts of the node and sp ngy unorganiz d mass of lympho d ti s ccupie the pe iphery In mamm ls the lymph id nod le with their germinal center l e in the per ph al eg o In both b rds and mamm l the germinal ent r how n t only m totic figu es but al o m ny lymph cytes n proc ss of degene ation and l rge ph go yt c cells wh ch ta n fragme t of lymphocyte or whole lymphocyte within their cytoplasm

Mammals Th lymph n des of mammals ary numbe s z form a d truct re in diffe nt pec s Ther appea to be ome rath r surp i ing d ffe n e n numbe f lymph n de in d ffer nt ki d f m mmals F ex mple, th dog s s id to h e ab t 60 the cow 300 man 465 and the h r e 8000 I th dog nd c w howe th lymph node a e el i ly la ge in m n nd the hor e they lat ely m ll Their h p lso vari s l the w fo m ta e the m e ter c nod s e l g nd arr w tta n l gth of al de mete In the bbit th me. nter n des m to h l d to n huge nod th pa re s a ell w gh g r l tim as much as ll the the n de c mb ed Th re a s m lar r a ge-

ment for the mesenteric nodes in some other rodents and in some carnivore The e pecie include the mole the dolphin the eal and the narwhal whale

The amount of connective tissue of the lymph node that is the degree of development of the capsule and trabeculae varies in different mammals It is weakly developed in the pig dog heep rabbit guinea pig and rat In man and in the horse the trabeculae of the medullary part are more strongly developed than those of the cortex Many mammals show a strong development of smooth muscle in the capsule and trabeculae as in the hor e sheep cow and dog The cow has an especially thick capsule and trabeculae

In some lymph nodes the cortex with its nodules is very sharply set off from the medulla with its more diffuse lymphoid tissue This is true of the cow In other animals the nodes seem to vary in this respect in different parts of the body or even in a rather haphazard manner whereas in still others such as the pig there may seem to be almost a reversal of arrangement with the nodular tis ue situated centrally and the diffu e tissue peripherally

Other lymphoid organs These include the tonsils thymus gland and pleen and in certain classes and groups of animals structures which are confined to such groups for instance the bur a of Fabricius in the birds a diverticulum from the lower end of the alimentary canal *See* SPLEEN THYMUS GLAND TONSIL

Tonsils The tonsils seem to be represented in the frog and toad by two large fossae palatinae invaginations of epithelium surrounded by dense masses of lymphoid tissue Smaller structures of simple construction al o are pre ent

In the posterior part of the buccal cavity of *Proteus* and *Salamandra* there are areas in which the epithelium is thickly infiltrated by lymphocytes

Among the reptiles *Lacerta agilis* shows definite tonsils in the pharynx with elongated lymph nodules occurring along epithelial invaginations and with an apparent lack of basement membrane and a complete intermingling of epithelial and lymphoid tissue near the surface Tonsil are seen also in the crocodiles

Birds not only have large aggregations of lymphoid tissue in the pharynx but often also a large esophageal tonsil The light taining germinal centers are een for the first time in birds

A ring of lymphoid tissue known as Waldeyer s ring con i ting of palatine pharyngeal and lingual tonsils is pre ent in many mammals as in man but other mammals may lack one or more of its component parts In the rat and mouse there are no palatine tonsils In the hare and rabbit pharyngeal ton ils are lacking The rabbit hare dog cat and heep apparently lack lingual ton ils

Tonsils of the hor e are peculiar in that they contain structures apparently identical with the Hassall corpu cles of the thymus gland

Spleen The spleen is an organ of dual nature belonging to both the blood va cular and the lymphatic system In the lower vertebrates it i actually within the wall of the alimentary canal In cyclo tomes it lies in the submuco a of tomach and intestine In the lamprey it is within the spiral valve Among the Dipnoi it is found within the stomach wall but in ela mobranchs and ganoids it is a separate stru ture attached to the me entery In fishes and amphibians it is active as an erythrocytopoietic and lymphocytopoietic organ Its function of forming lymphocytes is important al o in higher vertebrates (including man and other mammals) but its blood cell forming function is lo t and replaced by one of de truction of old or worn out red corpuscles and to some degree of blood torage *See* HEMATOPOIESIS

The lymphoid tissue of the spleen in higher vertebrates contains many nodules known as Malpighian bodie These usually contain active germinal centers

HISTOLOGY

Lymphoid tissue is a tissue in which the predominant cell type under normal conditions is the lymphocyte Lymphocytes are as ociated with reticular fibroblasts which form a delicate framework of fibers which can be demon trated by their affinity for ilver There usually are cells of other types present al o including macrophages (fixed and free) pla ma cells and occa ional eo inophilic granulocyte

Function The chief function of the lymphoid tissue is to produce lymphocyte In efferent lymphatic vessels those leaving the lymph node lymphocytes are considerably more abundant than in afferent lymphatics Lymphocytes are added to the lymph as it flows through the lymph node The lymphocyte content of veins coming from the node al o is greater than that of arteries g ing to them Apparently net ly formed lymphocytes al o migrate into the capillaries and mall veins A econd important function of lymphoid ti sue is protection against infection which it carries out by means of its phagocytic and antibody produ ing activity

Cellular composition Lymphocytes are of different size small medium and large The range in ize of the e three kinds however varie with different classes and even species of animal The large lymphocyte re emble very cl ely the tem cell of blood forming ti ue the hemocytobla t In fact lymphoid ti sue itself bears a c n iderable resemblance to hematopoietic ti ue and in lower vertebrates it is not alway possible to di tingui h ne from the other

The function of the lymphocyte them el i imperfectly known The tudy f c mparati e hi tology however eems to throw light on their probable role in higher f rms In many in e t brate the regenerati e p wer are mt h gr ater than in higher vertebrate It ha been hown that primiti e mesenchymat us and free lymph id ell often aggregate to f rm the variou organ pri

m rdia and e e t lly e en a c mpletely d ff ent ted s m l In some fl tw rms t has been f und that not only do new parts ri e f m u h lem t (ell th picuo s nucl oli a d b -ophili cyt plasm compar ble t the large lym phocyte) b t that the relat power f regenera t n in d ff e t peci s may be correlated with *th r lati e numbe s f su h cells* Thus whe e tl ey are um m s, as in *Pla a ia r* gener ti e power high. When th y are not so omm n as i *Procotyla* reg erat e po i low In flat rm tl e e ell ill f rm s h aried *tructur s as epith lium of* the gut, germ cell and bra

Altho gh the lymphocytes of m mmals d not h e h remark ble pote tial t es many workers ha e ho n that they an de elop into ri u th types of cells, clud ng macr phages which are larg ph gocytic cell some type f granular hit lls f the blood red blood ells and fib obla.ts, fib r f rm g cells The gge t *has been m de also that they may metam ph e* into p thel al ells in some locat ns. Th s e of *their mportant les n the highe v tebr te is* still r g n ti e r ell r pla g o e

Lymph vessels The lymph ap llari s the smallest lymph e els, form a d n e n tw k in almost e ery portu n f the body They appear to e d bl dly d co si t nly of n e d thel al l yer As th y u t t f rm l ger v els connect e ts, pp ar i the all Th bl d r nded end f lymphat c c pilla e re ly seen in the lacteal n th illi wh ch re i e the fatty f d fr m th testin l lumen a d he c e ntai n hyle, fluid m de milky by the p e ence f multitude of mi t dr plets of fat (F g. 7)

I larg r lymph tic s.el th re are m re c l lagen fibe s and lso som el st c and mo th muscle fiber In v el with a diameter f m re th n 0 ? mm th w ll ge e ally h w three layer wh ch b r the same names as th e in the blood e els, namely intima m dia and ad entitia In lymph ve ls the ad entit a i u *ually tl e thick t* layer and often contain mooth m scle cells as well as c ll g n us and ela tic c ct e ti sue fibers In the large t lymphatic e el the r ght lymphat c d t a d the th aci du t th med i more fully devel ped nd contain con derable mooth m scle

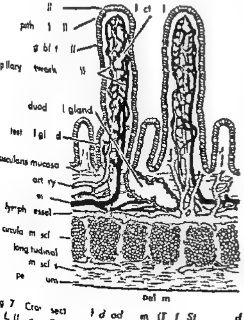


Fig 7 Cro sect l d od m (T f St d R. L U g G 1 2 l gy 3d d M G w-H ll 1957)

Lymph nodes The lymph nodes are m sses of lymph d ti sue with a pecial type of rch tecture. They are i t rp sed s way t ti ns in tl e cou se of the lymph tic tre m The e sel nter ng the n de re alled affer t tho e lea ing it re the effe e t e el

The c tex u lly co i t of rather den e lym phoid ti e mp sed of r u ded nodules, made up h fly f mall lymphocyt In the ent s f *the nod le are l ghter tai ing po ti the ger* m nal ce ters with m cr phages nd lymphocytes *of med um a d l rge ze frequently seen in* mit s.

Th medulla of the lymph node con i t f na tomosi g chan el r sinusoid thr gh which the lymph is our ing t ward the effe ent ve s ls a d f c rd of lympho d t e It i mo e po gy th the cort x

The lymph nod i su r unded by a c p ule con ist ng f collagen us and ela tic c nnecti e t ue fiber and ften ontai ing me mooth muscl At th hilum where the blood v ls f the *node ent r nd lea e nd fr m wh ch the ffer nt* lymph t c emerge th c n ecti ti sue f the c p ul p net ates well into the n d

PHYSIOLOGY

Lymph formation In ny gi en egion th fluid wh ch enter lymphat c ap llary may be that wh ch i lo e t the arte i lar or t th e u nd f a bl od c pill ry r t may b flu d rel t ely d st nt fr m e the Th r e ists a grad e t of p s u f m the t s ue fl d t the lum n f the lymph t c c p llary In edema s ch a be b ught abo t e periment lly by tre tme t w th yl l r by h at th gradie t is increa ed Th s p es- ur gr d nt i a importa t fa t i th f rm t n f lymph *S e E FMA*

A y fl d n wh ch filtr t e c ed ab rpt on th gh th wall f the bl d p ll ry is n rmally dr i d by the lymphat Expe imentally this s h w wh filt t n te s cre s d by nt e t an f s n by wa m ng f p rt

Function of the lymphatics The fu cti n of the lymph t s s t r m s ch cess fluid a d lso t turn to the blood tre m the pr te wh ll has e ped fr m the blood p ll r es Lymph ll cted f m lymph ti s of the k d ey l g nd ri c l g n s w ll f m th th r d t, ha been hown t t n thi prot in wh ch h b en l k d f om th blood c la y tem The e n te i cl d erum gl bul um albumi

and fibrinogen The filtrate from the blood capillaries consists of water and of sugar and salts in concentrations found within the blood stream plus the proteins in low concentration The salts and much of the water are reabsorbed by blood vessels whereas the protein together with some water and salt enters the lymphatics When the normal drainage of protein from the tissue spaces is prevented elephantiasis may result as when the lymphatics are obstructed in filariasis The result is massive edema of a part with dilatation and thickening of the lymphatic capillaries and an overgrowth of connective tissue *See* FILARIASIS

In addition to water ions small molecules and the large molecules of extravascular protein particles such as injected graphite or extravasated red cells also enter the lymphatic capillaries Such relatively huge structures pass between the cells

Composition and properties of lymph Basically the composition of lymph closely resembles that of the plasma Chemical and electrophoretic studies show that lymph contains all of the types of protein found in plasma but in lower concentration The composition of lymph varies to some extent from one part of the body to another Thus the lymph from the liver contains more protein than that from the skin

The ability of lymph to coagulate depends largely on its content of fibrinogen and prothrombin and this varies rather markedly In dogs the mean prothrombin level is 7 6 for leg lymph 51 2 for thoracic duct lymph and 93 2 for liver lymph There are no blood platelets in lymph and it is thought that thromboplastin generally considered necessary in clotting is formed at the time of clotting from precursors present in the lymph Calcium also needed in clotting is present in the lymph in slightly lower concentration than in the blood

The ionic content of lymph does not vary much from that of plasma (Table 1) Chloride and bicarbonate levels are higher in the lymph than in the plasma whereas total base is slightly lower

The glucose content usually is essentially the same in the lymph as in the blood Curiously the lymph of the kidney has a lower concentration of glucose When carbohydrate is fed or when an intravenous injection of glucose is made the concentration of this sugar in the lymph lags behind that in the plasma but eventually catches up when an equilibrium between plasma and lymph is attained Concentrations of amino acid creatinine and urea are approximately equal in lymph and plasma but in the kidney the urea of the lymph is slightly higher than that of the plasma It seems probable that some of the renal lymph comes from fluid reabsorbed from the distal and collecting tubules *See* KIDNEY URINARY SYSTEM

The lipids consist of neutral fat forming the chylomicrons and of cholesterol and phospholipid the latter two kinds of compounds being associated

Table 1 *Average values for the concentrations of electrolytes in lymph and plasma*

Substance or property	Source of lymph	Subject	Plasma	Lymph	Anesthetic
Sodium meq/liter	Thoracic duct	Man (5)	1?7	1?7	
	Cervical duct	Do	163	157	Nembutal
Potassium meq/liter	Thoracic duct[b]	Man (5)	5 0	4 7	
	Right lymph duct[d]	Dog (5)		5 4	Nembutal
Calcium meq/liter	Thoracic duct[b]	Man (5)	5 0	4 2	
	Thoracic duct	Dog (1)	5	4 6	Amytal
	Cervical duct[f]	Dog (11)	5 8	4 9	Nembutal
Chloride meq/liter	Thoracic duct[b]	Man (5)	96	98	
	Thoracic duct	Dog (1)	110	116	Amytal
	Cervical duct[f]	Dog ( )	116	1	Nembutal
Inorganic phosphorus mg%	Thoracic duct[b]	Man (5)	4 5	4 4	
	Thoracic duct	Dog (1)	4 3	3 6	Amytal
	Cervical duct[f]	Dog (3)	5 6	5 9	Nembutal
Carbon dioxide ml%	Cervical duct	Dog (7)	56 8	58 8	Nembutal
Carbon dioxide tension mm Hg	Cervical duct	Dog (7)	46 4	40 3	Nembutal
pH	Cervical duct	Dog (7)	7 34	7 41	Nembutal

Numbers in parentheses indicate number of subjects studied

[a] H R Bierman et al The characteristics of thoracic lymph duct in man *J Clin Invest* 3 637 649 1953

O H Lowry and F W Maurer quoted by C K Drinker and J M Yoffey *Lymphatics Lymph and Lymphoid Tissue* Harvard University Press 1941

[d] F C Courtice unpublished data

R M Arnold and L B Mendel Interrelationships between the chemical composition of the blood and the lymph of the dog *J Biol Chem* 7 189 11 1927

[f] J W Heim On the chemical composition of lymph from subcutaneous vessels *Am J Physiol* 103 3 558 1933

J W Heim and O C Leigh The carbon dioxide content and combining power and pH of cervical lymph *Am J Physiol* 11 6?9 04 193

briefly ...th protens t... f rm lip r t in. The qu tity f n tral fat d p nd n th f t ab p- t by th l t al f tl e inte tin and tl e am u ts f h lester l nd ph l l lip d ary with the am unts f pr t p e nt

Lymph flow Co t act lity f tl e walls f lym ph t es l m a d th r m mm ls pp e rs to be nly l ght a d t play a m r r le n lymph fl Th s in mark d ntr t t tl e d ti n in so e lo er erteb te part ula ly the *Ampl b a* m h h ll-de l ped p l atile lymph heart ur l g th r e of the lymphat c cl n els (Fig. 6) Th lymph fl w in mam s ls ppears t be ry l g l mp d with tl at in tl fr g The th r l w r t of fl w f the lymph n dog se T ble 2. It l ul ted that e tr a ular ul t l ol 50–100% f the pl m p o- t h d y (Table 2)

The p e f th lympl fl w ri ble e n ma g e lymph t l Becau e l mpl fl w tr petally it lear that th peripl e al lymph d r high r pr re th th t f rth l ng the essel M cle nt t n uch as th e f tl e l g m lk g may g tly re se the pre ur f the lymph i di d l r gi D ing c tr t f th m le the lymph t s t d t empty h as d ri g el t tl y fill ag I e e pe ime t p e w re ded fr m a lym ph t y t bel w the popl t l lymph n de of d g h n th mal s t t b t d g r p d fl xi d te o f the l g th p e e 1 68 m f ter

M em t f lymph pr re ually a de d t d rd d t n f t P e e m j d f th tl d t f th d ha bee d d s 6 4 m f wate mpa d w th a pre ur f 2.4 m i th t m l jug la n f th me d g S h a p d ff e pro- m tes fl w f m the th d t t th u ry tem

P e ures h bee rec d d f m a n mbe f diff e t lymph ti l Th t of th lymphatic

Table 2. A flow d p ot ont t f lymph f om ...ou lymph d cts l dog d *mb tal th l*

Lymph d ct†	Lymph flw ml h		Lymph prot g dy	% f t t l ant sc l pla m prot
Thora d t (4)	6 0	4 1	6 1	4 5
Right l mph d t (1)	3	3 7	0	3 6
Cerv l d ts (18)		8	1 3	4
Forel g d ts ( )	3 8	3 3	1	
Hindleg d ts (1?)		1 8	1 0	1 8

From C k D k d J M Y ff y *Lymph tic* *L ph d Lympl d Tu e*, d ed II d Un rs ty P ess, 19 6 ... g w ght f h mm l h gro p as ppro m tely l kg d t sc l plas prote g T tal lymph p from l g d cer l d ts l des both des † N mbers p re theses p es t th umbe f als up

apillar s is rather h gh h v g been re orded 42 6 cm f water (31 3 mm f Hg) in the capillary of the llu

Lymphatic system in immunity The lymph n des erve a filte ing out pla es f f reig par t l l cl d g microorg ni m bec use the lymph mes i to intim te ntact with the many phago yt c cells f the i u ids. Th e macro- phage are f both tl e f xed nd fr e wa d ri g type *S e* PHAGOCYTOSIS

In additi n to the pl ag cytic fu ct n perm me tal t di f a e dem trated that lympho d ti e p d antil d es If ant gen ucl s typh id bac lli h ep erythr ytes are injected into th p d f the f t f a e per me t l an m l nt b die begin t app ar in the effere t lymph es el of th popliteal node a few days lat r a d their t t r p dly nc ase t a ma m m a d tl n de ll S m i e t gat r ha e f und th t m t f th a tibody is with in the lymph tes rather th i tl e flu d The lympl n de how an inc a e i e of it ge min l c nte s a d there is in cre ed utput f lympl cyt s *S e* ANTIBODY

The a tu l p of t body f rmat n i lymph d t u is t well u derst d A n d r ble body of e id ce wo ld a ign the chief l to the pl ma cell ge erally abund t in lymp l d ti e rather th n t the lympl ocyt Ant gen inj ti h bee h wn t b g ab t t n pl ma ell p se i m ny in t ces The e t of fluo e t a t g ns d ant b d ffe ev dence tl t ant g n fixed by pla ma c ll lymph odes which are f rming a t b d e b t ot fi ed by lympl ocyt The i re ed mb f lymph yt s in nfecti a d th i pas ge t th bl d t m m y th s ha me gn fi an e not nne t d with antibody f r m t n

Cerebrospinal fluid Th ereb pin l fl d fills th t i l s f th brain d the p between th ar hn d m t d the p mate *Cerebro- spinal fluid* a l a l q id d ed from the c p lla y e l f the l r id pl which p m t tl e pa ge f w ter l tr lyt nd m ll m l cul s, but h ld b k the p t ns of the bl d Fl d p ng thr gh the w ll f th capillaries m t al g th gh l yer of ep thel m er g th p ll e T f protein are f u d n the m l c b p l fluid *S e* NERVOUS SYSTEM

By f the g ater p rt f th rebr pinal fl d ab b d t the f th ra h d ll Th lat h p betwe th reb pi l fl d d the l mph tic y t m f di certai g s wh h th fl id e c p s f m th m ges d te lymph tic p ll s. Th t m y p s by way f the a h d h th of th lfa t y erves t th bm f th na al c ty d ach ll erv l lymph tic essels. Arachn d er gs f the ry gangl l a e loc t wh ll p n l fl d m y h th lymphat n th m l an m l

Cl lly ch con tion m y e te by wh ch b t c ent the e i al

nervous system. They may also, in cases of meningitis or of hemorrhage, help to clear the cerebrospinal fluid of cells and of plasma protein.

Cerebrospinal fluid differs from other lymph in its low protein content, low cell content, and lower specific gravity (1.004–1.008). It contains no fibrinogen.

The cerebrospinal fluid has at least three functions: (1) it acts as a fluid buffer against shocks and jars of the central nervous system; (2) it serves as a reservoir in regulation of the cranial contents; and (3) it acts as a mechanism for exchange of gases and nutrients in the nervous system. In relation to these functions its properties are particular, but it may be considered as a specialized type of lymph. [W.A.W.]

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Lymphocytic choriomeningitis

A viral infection endemic in mice but occasionally transmitted to man, in whom it may produce a mild influenzalike disease or an aseptic meningitis. Sometimes encephalitis or even a fatal systemic disease may be produced.

Diagnosis of lymphocytic choriomeningitis (LCM) is by isolation of the virus from acute phase spinal fluid or blood, or by increases in serum antibodies.

Mice are the usual reservoir of virus; they may harbor it throughout life and transmit it to their offspring. Dust and food contaminated by urine or feces are probable vehicles of transmission to man; however, *Trichinella spiralis* can be infected experimentally and has been suggested as a possible means of transmission from animal to animal or through pigs to man. [J.L.M.]

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Lymphogranuloma venereum

A venereal disease caused by a virus of the psittacosis group. The infectious agent has been related to the lymphogranuloma psittacosis group by structure, development forms, staining, growth in the yolk sac, and antigenic components. The disease, also known as climatic bubo, is manifested in constitutional symptoms and acute or chronic tissue change in the inguinal and recto-anal region.

After venereal exposure, painless vesicles develop on the genital organs or anus. The infection may terminate here or it may progress to adenitis of the pelvic lymph nodes accompanied by fever and generalized symptoms, even pneumonitis. In the chronic stage plastic induration of the male genitalia or in the female vaginal and rectal stricture with fistula are typical.

Elementary bodies may be seen in cells from human lesions, and they are transferable to the white mouse by intracerebral inoculation. Past or present infection can be detected with complement fixation tests or, more commonly, by the intradermal Frei test. Subjective clinical and functional improvement has followed treatment with the antibiotic terramycin. In the United States the disease is more prevalent among Negroes than Caucasians. Serum surveys, early diagnosis and treatment, supervision of infected persons, and public education are important in prevention. See ANTIBIOTIC; ANTIGEN; LYMPHOGRANULOMA PSITTACOSIS GROUP; PSITTACOSIS; SKIN TEST; VIRUS.

[K.F.M.E.]

Lymphogranuloma psittacosis group

Viruses of psittacosis, ornithosis, lymphogranuloma venereum, certain localized infections of mammals, and inclusion blennorrhea, measuring 350–500 mμ in diameter, comprise this group that lies along an indistinct line dividing rickettsia from viruses. They stain with formol methylene blue or other basophilic dyes. All grow well in the embryonated egg and tissue culture. One heat-stable antigen is shared by all members, and the heat-labile antigens are specific for individual members. Many produce toxins. These viruses are isolated mainly by inoculation of mice or guinea pigs. The tissue and cellular tropisms vary considerably within the group. They are each susceptible to antimicrobial drugs to a somewhat different degree. See ANTIGEN; CULTURE, EMBRYONATED EGG; CULTURE, TISSUE; RICKETTSIALES; VIRUS. [K.F.M.E.]

Lynx

Any of several moderate-sized cats of the genus *Lynx*, family Felidae, characterized by long legs, short tails, tufts of hair on each cheek, and tufted, pointed ears. They are found in the Northern Hemisphere and Africa. Although the bobcat is also a lynx, in the United States the name is usually applied only to *Lynx canadensis*. The lynx is about 3 ft long, with a short, black-tipped tail and large feet. It occurs from Alaska across most of forested Canada, northern New England, northern Michigan, and southward in the mountains into Colorado.

The lynx is a cat of the undisturbed forest and seldom has much contact with man. Its principal food is the snowshoe rabbit or varying hare

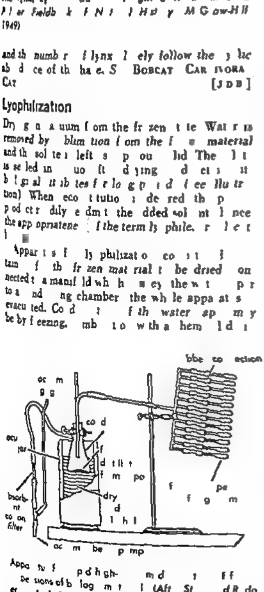
The lynx, ly   ad   l gth 3 ft (F m E L. Pl er Fieldb k f N t l H st y M G aw-Hill 1949)

and th number f lynx l ely follow the y lic ab d ce of th ha e. S BOBCAT CAR IVORA CAT [J D B]

Lyophilization

Dry g n a uum f om the fr zen t te Wat r is removed by blim tion f om the f n material and th sol te i left s p ou lid The l t is se led in uo (t d ying d et s it b l gi al it ib tes f r lo g p i d (ee Illu tr tion) When eco t tutio i de red th p p od ct r dily e dm t the dded sol nt l nce the app opriatene f the term ly phile. r l e t l

Appar t s f ly philizat o co s t f tain f th fr zen mat rial t be dried on nected t a manif ld wh h n ey the w t p r to a nd ng chamber the wh le appa at s evacu ted. Co d t f th water ap m y be by f eezing, mb t o w th a hem l d i



Appa tu f p d h gh- m d t f f be sions of b log m t l (Aft St d R dg er A J S ll f d m t l P pl f B t l ogy 4 h ed M G w H ll 1954)

cant r e acu t n by pu p g (ee illu trati n) In de ic t n f la ge m t f material it is ad antageou to p ly h t carefully t ha ten porati n a dryi g p c d

In elab ration of the p ri ip le myriad f ri f pp r tu ha e l en m de r ging in capacity fr m ll l b rat ry e uip t tal le f r p erving v ble lt re f mi r g r ther lls nd ti ue t l b rate de i t f r plant le pre ervati n f erum p l ma antibi ti s horm e b ea t milk nd fo d tuff S e MICRO-BIOLOGICAL METHOD [M]

B bl og aphy E. W Fl d r(*Fr Dry g (D y g by Sublim t o*) 1949 H J C. Harri (ed) *B l g l Appl tions f Fr e ing d Dry ng* 1954

Lyra

The Lyre a tronomy is a mmer n tellat on m ll b t imp rt nt Lyr has a fir t m gnit de tar Veg a na igat nal t and the m t br l ha t t in tl p rt of the ky Vega form with two faint t to tl e ea t n almo t perf ct q i lat al tri gl The southern ne n turn f rms w th thr b ight tar t the south n appro i mate p all l g am The s lting er ll figur emble a tort e mor than tr nged mu al n t ent How er rd ng t l gend Mercury mad the fi t lyr f m turtle h ll by plac ng tr g a o t Hen e the tw differe t r p e en tat n are t in mpat ble In thi con tellati n l the famou R g Nebul See CONSTELLATION NEBULAE, GASEOUS [C S Y]

Lysin

A term u ed n bi logy to de ibe sub ta ce th t will di pt a ll n th th rel a e f ome of its n tit e t U le the damage s mi or th n t le ds t the d ath f the cell Ly s ry in the a ge f h t pe es wh o e ell they will t t ck d n their eq m nt f r ces ry fac t rs f ly th immu ly n are t i te t n ther q rem ts E yth o yt s e lysed by w de i ty f hem al in lud ng w ter nd hy p rt n s lt l ti n whi h d plac the mot c p e u fr m th t of ot n ty Th y a e lso us ept bl t fa e act b t n e such a po n n M ny bact r a u h as the t phyl co c s d the t ept c s el b ate o or m re hemo-ly th t w ll ly e rythr cytes fr m rt i al tho gh n t all pec f nimals Th e p tt rns m y b u d n th t o m c cl s fi t on f mi o g m Th e r a numbe f ther lyti b ta ch ly zyme n ym in the ey q h m r nd t me e te t the b cte o-pl ge wh cl att k di r p c f b cte ia b t th e t ns a e t nt ly n pe fi s e they d p d th p e c of mmo c ll t t nt r cept n wh h d ot h we e d w th th l ed t mm ly S e BACTER O HAGE STAPH LOCOCCI S STREPTOCOC CUS

Immune lysins This is a term used in serology to designate an antibody that in the presence of complement and cofactors such as Mg (magnesium ion) and Ca^{++} (calcium ion) will disrupt a particular type of cell with the release of some of its constituents This action is in accord with the principles of serologic specificity and is to be distinguished from the more general actions of other lytic chemicals Immune lysins are also classified according to the general class of cell attacked hemolysins are antibodies lysing erythrocytes while bacteriolysins cause the lysis of bacterial cells Hemolysins against various foreign erythrocytes occur normally in many sera the Forssman and other heterophile antibodies and the blood group isoantibodies constitute special instances High titers of hemolysins may also be produced by immunization with erythrocytes and rabbit antibody against sheep erythrocytes is an important laboratory reagent the so called amboceptor in complement fixation tests For example sheep erythrocytes injected into a rabbit produce antibodies in the rabbit against the sheep red blood cells The lysis of erythrocytes releases hemoglobin which may be quantitated by eye or by a colorimeter *See* ANTIBODY ANTIGEN COMPLEMENT (SERUM) COMPLEMENT FIXATION TEST HEMOGLOBIN HETEROPHILE ANTIGEN LYTIC REACTION

Pfeiffer reaction This is an example of a bacteriolytic reaction carried out with gram negative bacteria such as cholera vibrios which are especially susceptible to the lytic action of specific antibody complement Mg and Ca This reaction may be carried out in vivo (Pfeiffer's system) or in vitro and is a valuable aid in diagnosis An analogous reaction is given by the spirochetes of relapsing fever Although demonstrable instances of bacteriolysis occur it is not clear whether all the bactericidal actions of antibody and complement are necessarily preceded by lysis *See* CHOLERA VIBRIO [H P T]

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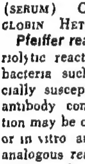
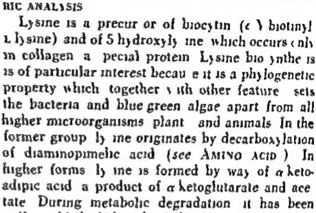
Lysine



Phy l constants of L-lysine 2 C
pK_1 (COOH) 2.18, pK_2 (NH) 8 pK_3 (NH) 1 3
Isoelectric point 9 4
Opt l rot ( ) (H O) +13.5 [ ] (N HCl) + 0
Solubility (g/100 ml H O) (very soluble)

An amino acid considered essential for normal growth of animals The amino acids are characterized physically by the following (1) the pK_1 or the dissociation constant of the various titratable groups (2) the isoelectric point or pH at which a dipolar ion does not migrate in an electric field (3) the optical rotation or the rotation imparted to a beam of plane polarized light (frequently the D line of the sodium spectrum) passing through 1 decimeter of a solution of 100 grams in 100 ml (4) solubility *See* EQUILIBRIUM IONIC ISOELECTRIC POINT OPTICAL ACTIVITY SPECTROPHOTOMETRIC ANALYSIS

Lysine is a precursor of biocytin (ε-N-biotinyl L lysine) and of 5 hydroxylysine which occurs only in collagen a special protein Lysine biosynthesis is of particular interest because it is a phylogenetic property which together with other features sets the bacteria and blue green algae apart from all higher microorganisms plants and animals In the former group lysine originates by decarboxylation of diaminopimelic acid (*see* AMINO ACID) In higher forms lysine is formed by way of α keto adipic acid a product of α ketoglutarate and acetate During metabolic degradation it has been well established that the following sequence takes place lysine → α aminoadipic acid → α ketoadipic acid → glutaric acid → α hydroxyglutarate → α ketoglutarate The conversion of lysine to α aminoadipate requires a complex series of reactions including an intramolecular transamination there is considerable evidence for the following



See TRANSAMINATION [E A AD]

Lyssacinosa

An order of the subclass Hexasterophora in the class Hexactinellida In the sponges the parenchymal megascleres are typically free and unconnected but are sometimes secondarily united The parenchymal megascleres vary from hexactins to diactins the latter are always present and sometimes exclusively so *Leucopsacus Euplectella Rossella* and *Rhabdocalyptus* are examples of this order *See* HEXACTINELLIDA HEXASTEROPHORA [W D H]

Lytic reaction

A term used in serology to describe a reaction that leads to the disruption or lysis of a cell The best example is the lysis of sheep red blood cells by specific antibody in and complement in the presence of Ca (calcium ion) and Mg (magnesium ion) a reaction that forms the indicator

tem of the st d rd Wa rmann test for syph ils as ll ther c mplement fi at n re ctions. I thi example ly is result in the release of cel l lar h m gl b t t *the medium the re ction* m y b f ll ed by i ual r in-trum nt l e-tima ti f the decrea ed ll turbidity r the increa ed l of the med um d e t the free hemogl bin By appr p te cho e f graph p pers and coordi tes th entire se f h moly is r a range of reagent c n entrat ns may be predi ted fr m tw or m re accur te mea urements in the intermedi ate range As outlined by M M Mayer nd his associates *the mechani m of the lytic react on of* red cells is a mplex multi tepped ne

[H P T]

B bl g aphy M M Mayer Studies on the mechan m of hem lys s by antibody and complement *Prog in Allergy* 5 215 1958